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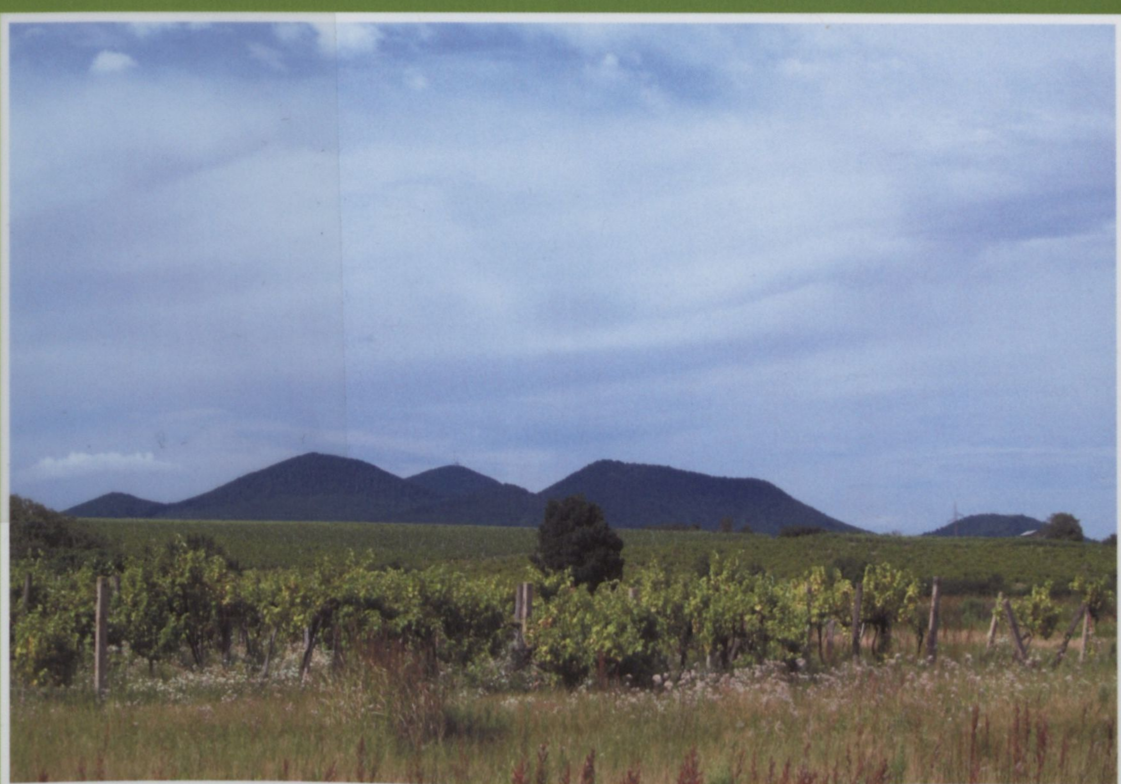

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Minerals and wines: Tokaj Mts., Hungary and Slanské vrchy Mts., Slovakia

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1.1. Geological setting of the Tokaj and Slanské vrchy Mts. in the frame of the Carpathian Volcanic Range

The volcanic rocks in the Tokaj and Slanské vrchy Mts. are of Upper Miocene age (mostly Badenian–Sarmatian). These volcanic units are parts of the Neogene–Quaternary intermediate-acidic calc-alkaline volcanic range of the Carpathians, and more specifically they belong to the Western Carpathian segment of that range (Fig. 1). The geodynamic and magmagenetic aspects of the Neogene to Quaternary volcanism of the Carpathians has been discussed by several authors in details (Kaličiak *et al.*, 1989; Lexa *et al.*, 1993; Kaličiak, 1994; Pécskay *et al.*, 1995, 2006a; Lexa & Konečný, 1998, Seghedi *et al.*, 2004a, 2004b, 2005). The widely accepted picture involves that the Carpathian volcanic arc has been developed in relation to the southwestward subduction of the Penninic oceanic crust of the Carpathian flysch basins. The subduction was generated by the northeastward escape of two continental lithospheric blocks from the Alpean collision zone (*e.g.* the ALCAPA and Tisza–Dacia microplates that have been amalgamated during the Upper Cretaceous collision of Africa and Europe in the Western Tethyan realm). Soft collision occurred in the Lower Miocene in the Western Carpathians and mostly in the Upper Miocene in the Eastern Carpathians. Thus – *sensu stricto* – the formation of the intermediate-acidic volcanic units of the Carpathians can be considered as the result of a syn- to post-collisional volcanism. The combined effect of the transtensional-transpessional tectonism, roll-back of the subducting slab and possible slab break-off processes (from northwest to southeast) resulted in opening of back-arc-like basins (*e.g.* Pannonian Basin, Transsylvanian Basin and several smaller ones), as well as temporal shift of volcanism from the West to the East and from the Northwest to the Southeast (Săndulescu, 1988; Szabó *et al.*, 1992; Csontos *et al.*, 1992, 1995; Pécskay *et al.*, 1995, 2006a, Vass, 1998; Lexa, 1999). The formation of the intermediate-acidic volcanism lasted from the Lower Miocene until the end of Miocene in the Western Carpathians, whereas development of the arc along its Eastern part started in the Middle Miocene and ended in recent times (<0.05 Ma). The last eruptions in the southeastern segment of the Eastern Carpathian volcanic range occurred about 42–11 Ka ago in the Ciomadul Massif. In addition to the intermediate-acidic volcanism, two additional types of volcanism occurred in the Carpathian–Pannonian Region (including both the Carpathian thrust-and-fold arc and the back-arc type basins):

1. Areal type calc-alkaline acidic volcanism. It is represented by areally extended sheets of dacite-rhyolite tuffs and ignimbrites associated with extrusive domes in the Pannonian and other basins of the Carpathian realm, largely covered by younger sediments. The volcanic activity of this type ranges

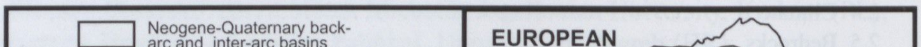
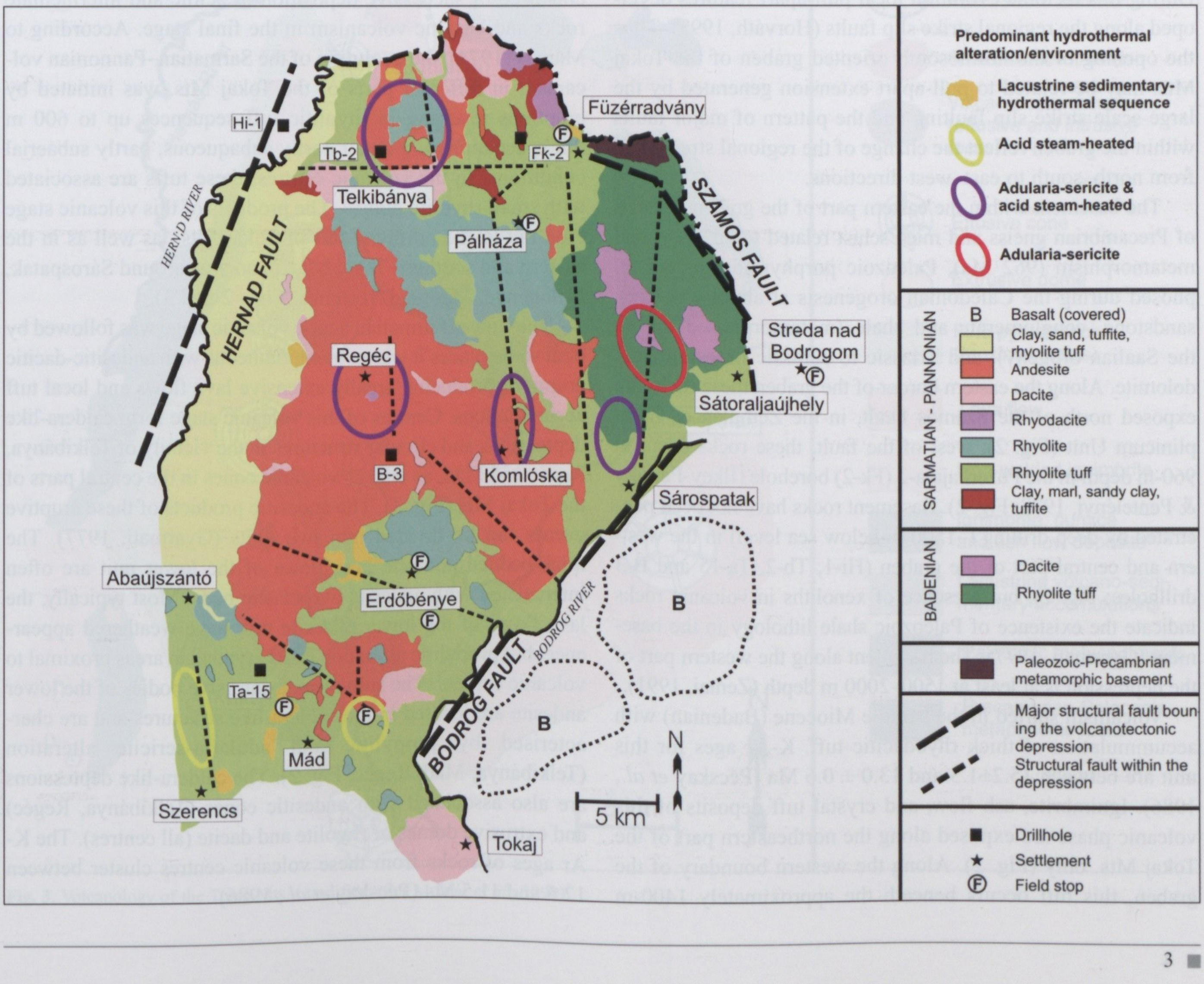


Fig. 1. Location of the Tokaj Mts. and Slanské vrchy Mts. in the Carpathians.

from Eggenburgian till Lower Sarmatian and the emplacement of volcanic products progressed from the south-west to north-east. From the petrological viewpoint, the rocks are of the crustal origin being formed by anatexis owing to overheating of the crust in extensional regime by the mantle diapirism and penetrating mafic magma of asthenospheric source.

2. Alkaline to ultraalkaline volcanism. This type indicates the continuing extension in the back-arc space. It is represented by diatremes, maars, scoria cones and lava flows. Occurrences of these volcanic units are restricted to areas of limited extension as monogenetic volcanic fields such as the Balaton Highland and the Little Plain (Kisalföld) area in Western Hungary and the Nógrád Volcanic Field in Northern Hungary. Scattered occurrences are also known in the Western Pannonian Basin and in Eastern Carpathians (Perşani Mts.), too. This type of volcanism was most widespread in the Carpathian–Pannonian Region between 8 and 0.5 Ma. Its origin is related to various mantle sources whose melting was triggered by small asthenospheric thermal plumes or by decompressional processes.

Fig. 2. Geology and major hydrothermal areas of the Tokaj Mts.



From the point of view of hydrothermal processes, metallogenesis, and volcanic raw material deposits, the calc-alkaline intermediate-acidic volcanism has the primary importance in the Carpathians. The famous epithermal gold-silver deposits (*e.g.* Banská Štiavnica [Schemnitz / Selmecbánya], Körmöcbánya [Kremnitz / Kremnica], Roşia Montană [Verespatak], among many others) were formed in these units and current mineral exploration still finds interesting and promising targets in the old mining fields of the Carpathian volcanic range.

1.2 General geology and mineral deposits of the Tokaj Mts.

1.2.1 Geology and volcanism

The Tokaj Mts. comprise the southern part of the Slanské–Tokaj Unit, a volcanic range which is about 150 km long and 15 to 20 km wide in northeastern Hungary and eastern Slovakia (Fig. 1). The Tokaj Mts. covers approximately 1200 km^2 area and has a moderate topographic relief. The highest peaks are between 700 and 900 m above sea level. The center of the Tokaj Mts. is located south of Regéc (Fig. 2) at 21°24' E, 48°19' N.

The Middle–Upper Miocene (Badenian–Sarmatian–Pannonian) volcanic-sedimentary sequence of the Tokaj Mts. fills up an approximately 2 km deep, N–S oriented graben-like volcano-tectonic structure and is bordered by the north-northeast trending Hernád Fault and the northwest trending Szamos Fault (Pantó, 1968; Gyarmati, 1977). The southeast margin of the graben is bordered by the northeast-trending Bodrog Fault. These faults can be related to the major strike-slip, left-lateral Mid-Hungarian Line of the Pannonian Basin. Within the graben, the major faults have north–south orientations or are aligned nearly perpendicular to the Bodrog Fault (Fig. 2).

The strike-slip movement along the Mid-Hungarian Line caused about 300 km northeastward displacement of crustal units during the Palaeogene–Early Miocene (Fig. 1). Paleomagnetic data indicate that during the Miocene an approximately 30° counter-clockwise rotation occurred in some regions of the Tokaj Mts. (Balla, 1987; Csontos *et al.*, 1991). The $\sigma 1$ direction of the regional stress field in the Pannonian area changed from north to the east after the Badenian (Csontos *et al.*, 1991, 1992). This change in the stress field was caused by the migration of the Carpathian subduction front from west to east. This migration was also accompanied by the change of subduction from oblique in the west to perpendicular in the east. During this tectonic evolution local pull-apart features developed along the regional strike slip faults (Horváth, 1993). Thus the opening of the north–south oriented graben of the Tokaj Mts. may be related to pull-apart extension generated by the large-scale strike slip faulting and the pattern of major faults within the graben reflect the change of the regional stress field from north–south to east–west directions.

The basement within the eastern part of the graben consists of Precambrian gneiss and mica schist related to an Assyntian metamorphism (962 Ma), Paleozoic porphyroids (metamorphosed during the Caledonian orogenesis at about 450 Ma), sandstone, conglomerate and shale (metamorphosed during the Saalian orogeny), and Triassic to Jurassic limestone and dolomite. Along the eastern border of the graben these rocks are exposed north of the Szamos Fault, in the Zemplén or Zemplinicum Unit (Fig. 2); west of the fault, these rocks occur at 960-m depth in the Füzérkajata-2 (Fk-2) borehole (Ilkey-Perlaky & Pentelényi, 1978; Fig. 2). Basement rocks have not been penetrated by deep drilling (–1500 m below sea level) in the western and central part of the graben (Hi-1, Tb-2, Ta-15 and B-3 drillholes; Fig. 2), but presence of xenoliths in volcanic rocks indicate the existence of Paleozoic shale lithology in the basement (Gyarmati, 1977). The basement along the western part of the depression is at least at 1500–2000 m depth (Zentai, 1991).

Volcanism started in the Middle Miocene (Badenian) with accummulation of thick rhyodacitic tuff. K-Ar ages for this unit are between 15.2±1.3 and 13.0 ± 0.6 Ma (Pécskay *et al.*, 1986). Ignimbrite, ash flow, and crystal tuff deposits of this volcanic phase are exposed along the northeastern part of the Tokaj Mts. only (Fig. 2). Along the western boundary of the graben, this tuff occurs beneath the approximately 1400-m thick younger sedimentary and pyroclastic rocks. The eruptive centers of the Badenian tuff are related to the northwest trending Szamos Fault.

The early eruptive phase was followed by graben subsidence and marine transgression from the northeast. The andesitic and dacitic volcanic rocks succeeding this stage were mostly emplaced in submarine environment, resulting in various types of peperitic and brecciated rocks intercalated with shallow marine clays, marls and fine sands. These submarine volcanic accumulations are known from drilling in the central part of the Tokaj Mts. at depths below 800 m (B-3 drilling, Fig. 2). Small and shallow subvolcanic andesitic-dacitic intrusions were also associated with the Badenian volcanic activity and these intrusions now crop out in the northeastern part of the Tokaj Mts. or are known from the deepest parts of the Telkibánya-(Tb-)2, Füzérkajata- (Fk-)2 and Tállya- (Ta-)15 drillings (Fig 2.).

At the end of the Badenian, volcanic activity temporarily ceased and uplift of various segments of the basement resulted in the regression of the Badenian Sea. Deposition of shallow marine-brackish water clay, marl, sand and reworked volcanic material was restricted to small basins in some parts of the Tokaj Mts.

The Sarmatian–Pannonian (Upper Miocene) volcanic phase consisted of successive deposition of acidic and intermediate rocks and basaltic volcanism in the final stage. According to Mátyás (1974), the evolution of the Sarmatian–Pannonian volcanism in different parts of the Tokaj Mts. was initiated by eruptions resulting in rhyolitic tuff sequences up to 600 m thick, accumulating under partly subaqueous, partly subaerial conditions. In the volcanic centres, these tuffs are associated with small rhyolite domes. The products of this volcanic stage crop out in the northern part of Tokaj Mts., as well as in the eastern and southern Tokaj Mts. in an area around Sárospatak, Erdőbénye, Mád and Szerencs (Figs. 2 and 3).

The Lower Sarmatian acidic volcanic stage was followed by or at some places it was contemporaneous with andesitic-dacitic eruptions producing areally extensive lava flows and local tuff accumulations. Centres of this volcanic stage form caldera-like depressions and circular structures in the vicinity of Telkibánya, Regéc and Mád, as well as volcanic cones in the central parts of the Tokaj Mts (Fig. 3). The andesitic products of these eruptive events can be divided into two units (Gyarmati, 1977). The thick-bedded andesite lava flows of the lower unit are often intercalated with andesite pyroclastic beds. Most typically, the lava flows of the lower andesite unit have weathered appearance, but propylitic alteration is also typical in areas proximal to volcanic centers. The subvolcanic-intrusive bodies of the lower andesite are located in the caldera-like structures and are characterised by propylitic and adularia-sericite alteration (Telkibánya, Mád, Regéc, Fig. 2). The caldera-like depressions are also associated with andesitic cones (Telkibánya, Regéc) and extrusive domes of rhyolite and dacite (all centres). The K-Ar ages of rocks from these volcanic centres cluster between 12.5 and 11.5 Ma (Pécskay *et al.*, 1986).

During the major stages of the Sarmatian andesitic volcanism, some areas of the Tokaj Mts. were still covered by a shallow sea. Therefore, tuffaceous accumulations are often well-bedded and intercalated with siliciclastic-pelitic sedimentary rocks deposited in brackish water.

Synchronously with or succeeding the accumulation of the lower andesite units, rhyolitic dome-flow centres formed independently between Telkibánya and Sárospatak, as well as in the vicinity of Erdőbénye and Mád (Figs. 2 and 3). The most typical K-Ar ages of these rocks are between 10 and 12 Ma (Pécskay *et al.*, 1986).

The late stage of volcanic activity was characterised by either pyroxene andesite lavas or local dacite-rhyolite products. The andesitic lava flows occurring at higher elevations in the western and central part of the Tokaj Mts. form the so-called upper andesite unit, and they are correlated with the emplacement of andesitic dykes (Telkibánya, Mád). Dacitic extrusions and intrusions of late stage volcanism occur sporadically in the area of the Tokaj Mts.; the most important occurrence is at town of Tokaj (Fig. 2). K-Ar ages of rocks formed during the late, Pannonian stages of volcanic activity are mostly between 9.5 and 11 Ma (Pécskay *et al.*, 1986).

The olivine basalt of the final stage of volcanism in the Tokaj Mts. (9.4±0.5 Ma; Pécskay *et al.*, 1986) is not exposed; it is covered by Pannonian and younger sediments and is known only from drillings in the vicinity of Sárospatak along the eastern boundary of the Tokaj Mts. (Figs. 2 and 3).

The Sarmatian–Pannonian volcanic cycle shows a more differentiated character as compared with the Badenian stage (Gyarmati, 1977). Both volcanic cycles started with acidic products and evolved to an intermediate-basic composition. However, the full rhyolite–rhyodacite–dacite–acidic pyroxene/amphibole andesite–pyroxene andesite series developed only during the Sarmatian–Pannonian cycle. According to Gyarmati (1977), Póka (1988) and Szabó *et al.* (1992), the petrochemical characteristics of these volcanic rocks have

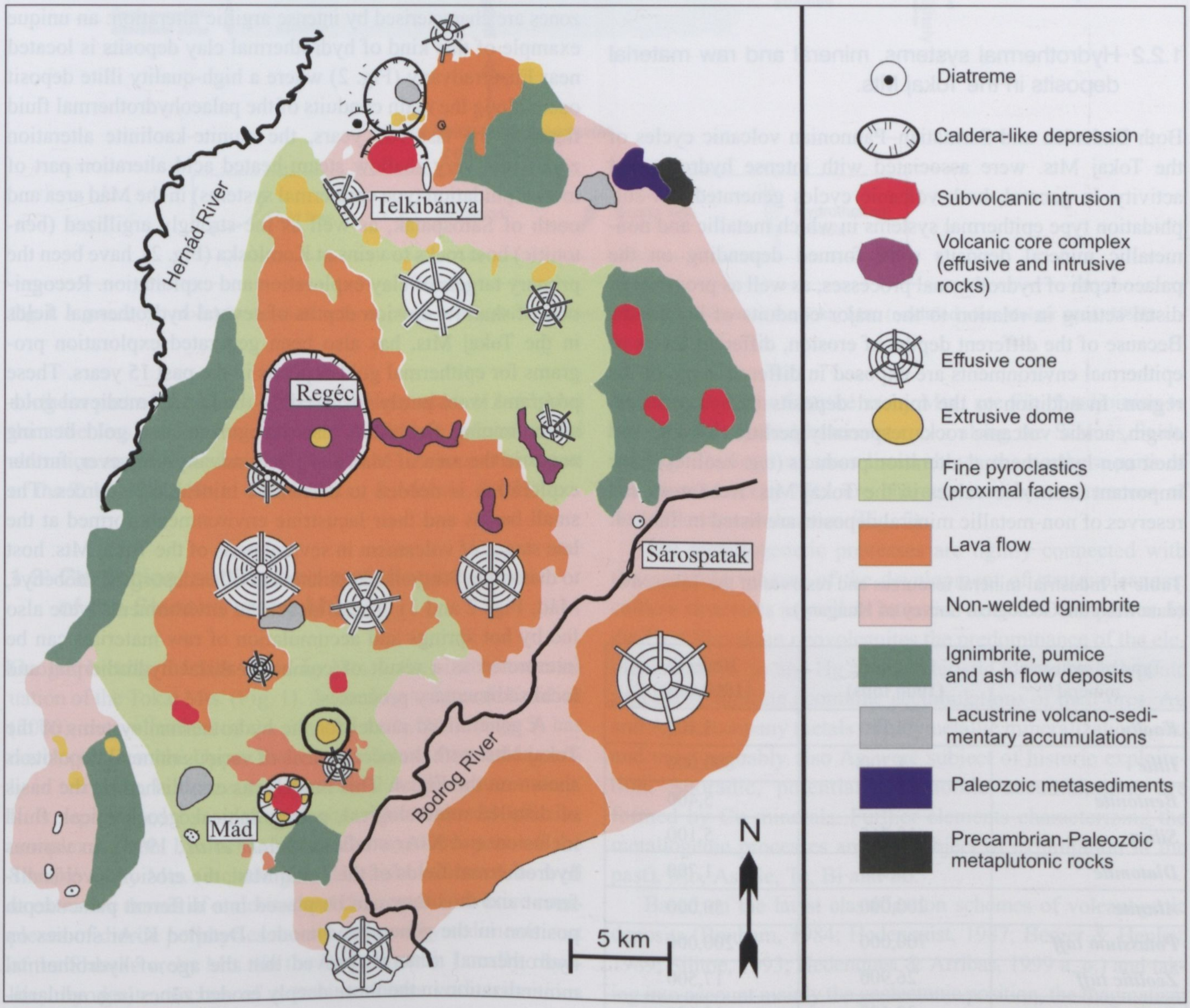


Fig. 3. Volcanology of the Tokaj Mts. (modified after Molnár *et al.*, 1999).

calc-alkaline signature with transitional character between island-arc and active continental-margin magmatic series. However, the rocks show much diversity, with high-K character (K_2O > 2.5 wt%) for rhyolite and some dacite and medium K-character (0.75–2.5 wt% K_2O) for andesite and dacite.

Mátyás (1974) suggested that the temporal variation in the composition of volcanic rocks originated from different levels of secondary magma chambers. Szabó *et al.* (1992) concluded that the bimodal character of volcanism indicates the existence of different magma chambers for different rock types, or a different degree of contamination in the same magma chamber. The initial $^{87}Sr/^{86}Sr$ (0.7060–0.7135), $^{134}Nd/^{144}Nd$ (0.51221–0.51255) and Pb isotopic ratios presented by Salters *et al.*, (1988) and Downes *et al.* (1995) indicate a strongly contaminated character of the volcanic rocks in the Tokaj Mts. The isotopic characteristics most probably resulted from the contamination of metasedimentary or acid meta-igneous upper crust in a mantle-derived melt which composition was already modified by the subducted slab.

1.2.2 Hydrothermal systems, mineral and raw material deposits in the Tokaj Mts.

Both Badenian and Sarmatian–Pannonian volcanic cycles of the Tokaj Mts. were associated with intense hydrothermal activity. In general, both volcanic cycles generated low-sulphidation type epithermal systems in which metallic and non-metallic mineral deposits were formed depending on the palaeodepth of hydrothermal processes, as well as proximal or distal setting in relation to the major conduits of hot fluids. Because of the different depths of erosion, different levels of epithermal environments are exposed in different parts of the region. In addition to the mineral deposits of hydrothermal origin, acidic volcanic rocks, especially perlitic rhyolite, and their non-hydrothermal alteration products (*e.g.* zeolites) have important economic values in the Tokaj Mts. Resources and reserves of non-metallic mineral deposits are listed in Table 1.

Table 1. Industrial mineral resources and reserves of the Tokaj Mts. (data from the Geological Survey of Hungary).

Type of industrial mineral	Resource (1000 tons)	Reserve (1000 tons)
Kaolin	8,200	3,100
Illite	1,700	800,000
Bentonite	7,700	5,400
Silica	10,765	5,100
Diatomite	5,000	1,700
Alunite	200,000	50,000
Potassium tuff	700,000	200,000
Zeolitic tuff	26,900	17,500
Perlite	30,500	15,100

The location of the most strongly mineralized zones is controlled by the major faults and volcanic centres; most commonly their orientation is elongated in a north–south direction. The hydrothermal alteration zones at Telkibánya, Regéc, Komlóska, north of Sárospatak and around Mád are characterized by strong potassium anomalies. Chemical analyses of altered rocks from these areas contain above 5–8 wt% K_2O (Széky-Fux, 1970; Gyarmati, 1977). These hydrothermal zones with sulphide-poor quartz veins surrounded by adularia-sericite alteration (resulting in potassium anomalies) were the sites of the medieval gold and silver mining at Telkibánya and north of Sárospatak (Fig. 2). In similar zones at Komlóska and around Regéc (Fig. 2), exploratory pits associated with the old mining activity can also be found. The adularia-sericite alteration zones have been formed at about 200–500 m palaeodepth in relation to the palaeogroundwater-table, most typically in the 200–250 °C temperature zone of the hydrothermal convection cells driven by small andesitic and dacitic intrusions (Molnár, 1994; Molnár & Zelenka, 1995; Molnár *et al.*, 1999). Shallower zones are characterised by intense argillic alteration: an unique example of this kind of hydrothermal clay deposits is located near Füzérradvány (Fig. 2) where a high-quality illite deposit occur along the main conduits of the palaeohydrothermal fluid flow. In the last 100 years, the alunite-kaolinite alteration zones (the very shallow steam-heated acid alteration part of low sulphidation type epithermal systems) in the Mád area and north of Sárospatak, as well as the strongly argillized (bentonitic) host rocks to veins at Komlóska (Fig. 2), have been the primary targets of clay exploration and exploitation. Recognition of shallow erosion depths of several hydrothermal fields in the Tokaj Mts. has also been generated exploration programs for epithermal gold deposits in the past 15 years. These programs were partly focussed on the known medieval gold-silver mining fields but also recognized new gold bearing zones in the area of Mád and Füzérradvány. However, further exploration is needed to determine mineable resources. The small basins and their lacustrine environments formed at the late stages of volcanism in several parts of the Tokaj Mts. host to diatomite, bentonite, kaolinite and silica deposits (Erdőbénye, Mád; Figs 2 and 3). These lacustrine environments were also fed by hot springs and accumulation of raw materials can be interpreted as a result of combined distal hydrothermal and local sedimentary processes.

A generalized model for the hydrothermal systems of the Tokaj Mts. with the occurrences of various mineral deposits is shown on the Fig. 4. This model was established on the basis of detailed mineralogical, petrographical, geochemical, fluid inclusion and K-Ar studies (Molnár *et al.*, 1999). In various hydrothermal fields of the Tokaj Mts., the erosion level is different and thus they can be placed into different palaeodepth position in the generalized model. Detailed K-Ar studies on hydrothermal minerals proved that the age of hydrothermal mineralization in the more deeply eroded zones (*e.g.* adularia-sericite alteration zones with Au-Ag accumulations) in the

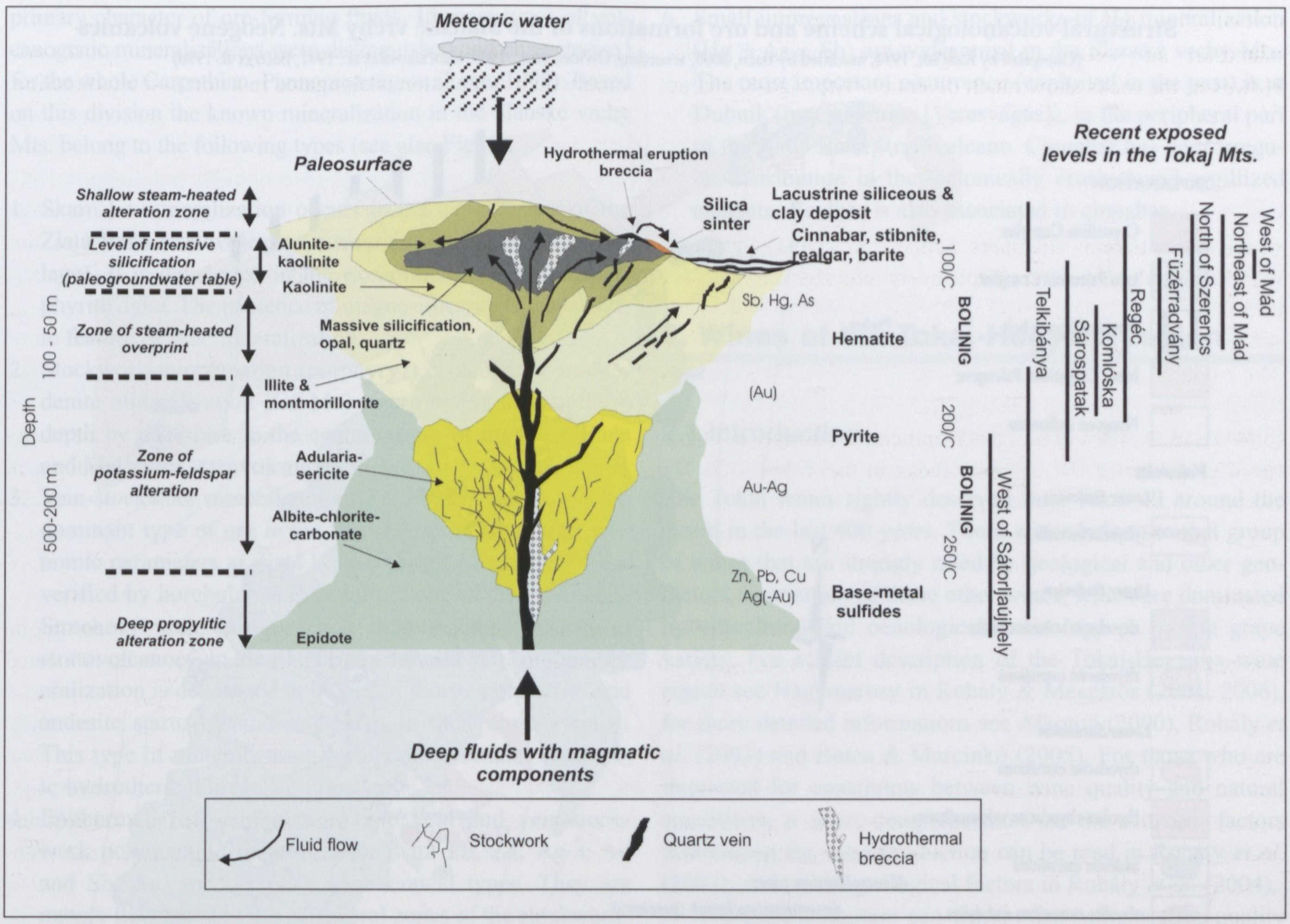


Fig. 4. A generalized model for the shallow levels of the low sulphidation type epithermal systems of the Tokaj Mts. (modified after Molnár *et al*., 1999).

northern part of the Tokaj Mts. are slightly older (12–13 Ma) than the less eroded hydrothermal fields (*e.g.* steam-heated alteration zones with alunite and kaolinite) in the southern part of the Tokaj Mts. (10–11 Ma; Pécskay & Molnár, 2002).

1.3 Geological setting and metallogeny of the Slanské vrchy Mts.

Geographically, the Slanské vrchy Mts. is the northern continuation of the Tokaj Mts. (Fig. 1). According to Lexa & Kaličiak (2000), the volcanism of the Slanské vrchy Mts. (Fig. 5) has developed from the Upper Badenian to Lower Pannonian partly in terrestric, but prevailingly shallow marine environment. It is represented by small andesite volcanoes and effusive complexes with hyaloclastites in the southern part of the Slanské vrchy Mts. (including the Hradisko volcano), as well as extrusive domes of andesites and dacites and intrusive complexes of diorite porphyries mostly covered by sediments east of the Slanské vrchy Mts. (in the Brehov area). Locally, rhyolite, rhyodacite, dacites of extrusive domes with transitions into the lava flows also occur in the Zemplín horst area (the eastern part of the Slanské vrchy Mts., see Fig. 5, adjoining to the area of exposed basement rocks along the Szamos Fault, see Fig. 2). Apart of areas listed above, the northern parts of the Slanské vrchy Mts. are characterized by occurrences of andesitic stratovolcanoes (Fig. 5).

The metallogenetic processes are tightly connected with the particular phases of the development of stratovolcanoes, caldera structures as well as intrusive-extrusive complexes. In the East-Slovakian neovolcanites the predominance of the elements Zn, Pb, Sb and Hg is characteristic for the metallogenic processes, forming economic accumulations of their ores. Au and Ag accompany metals of polymetallic mineralizations, Au and most probably also Ag were subject of historic exploitation. Sporadic, potentially economic accumulations are formed by Cu minerals. Further elements characterizing the metallogenic processes are Fe (subject of exploitation in the past), Mo, As, Se, Te, Bi and Sn.

Based on the latest classification schemes of volcanogenic deposits (Bonham, 1984; Hedenquist, 1987; Berger & Henley, 1989; Silitoe, 1993; Hedenquist & Arribas, 1999 a. o.) and taking into account mainly the geotectonic position, the magmatism type, the relation to subvolcanic magmatic-intrusive systems and

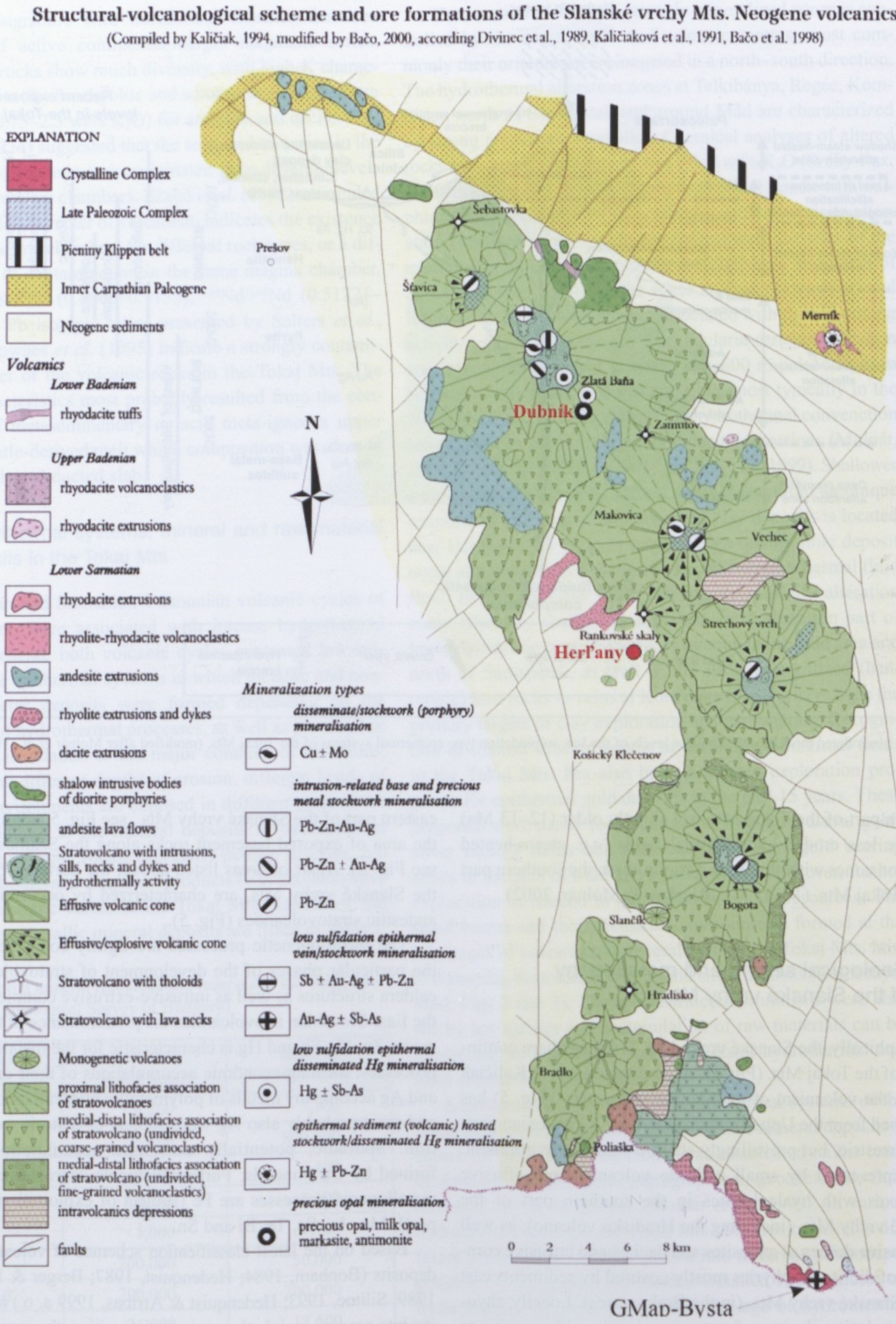


Fig. 5. Volcanology and mineralization of the Slanské vrchy Mts.

primary character of ore-forming fluids, 15 main types of volcanogenic mineralizations were distinguished and characterized for the whole Carpathian–Pannonian region (Lexa, 1999). Based on this division the known mineralization in the Slanské vrchy Mts. belong to the following types (see also Fig. 5):

1. Skarn Fe mineralization occurs in the central zone of the Zlatá Baňa stratovolcano (surroundings of Zlatá Baňa village). It is developed in the exocontact of a diorite porphyrite dyke. The presence of magnesioferrite is the specific feature of this mineralization.
2. Stockwork-impregnation (porphyry?) chalcopyrite-molybdenite mineralization (Cu-Mo) was found at about 600 m depth by drillholes in the central zones of the Zlatá Baňa and Makovica starovolcanoes.
3. Vein-stockwork mineralization (Zn, Pb, Cu, Au, Ag) is the dominant type of ore in the Slanské vrchy Mts. with economic parameters at Zlatá Baňa. Further occurrences were verified by boreholes in the central zone of the Makovica, Strechový vrch (Bačkov) and Bogota (Malé Ozorovce) stratovolcanoes. In the Zlatá Baňa deposit, 90% of the mineralization is developed in bodies of diorite porphyries and andesite startovolcanic sequences in their close vicinity. This type of mineralization locally also contains magmatic-hydrothermal breccia chimneys.
4. Epithermal, low-sulphidation type vein and vein-stockwork polymetallic mineralization with Pb, Zn, Ag ± Au and Sb, Au, Ag ± Pb, Zn geochemical types. They are mainly developed in the peripheral zones of the stockwork-polymetallic mineralization connected with intrusions. These epithermal ores occur in the central zone of the Zlatá Baňa stratovolcano, where stibnite was already mined in the past. In the present level of erosion, epithermal mineralization is exposed in three vein structures in the northern part of the startovolcano and in one interpreted structure in its southern margin. Vein structures have N–S orientations and are steeply dipping to west. The main, nearly monomineralic veins are filled up by stibnite. The immediate surrounding of the veins is intensively pyritized and silicified. The Au-Ag mineralization preferably bounds to this part of structures. The native Au was found in quartz but also in stibnite as inclusion. From Ag minerals stephanite and diaphorite were identified. The uppermost parts of epithermal systems are locally preserved, being represented with characteristic fabric of quartz and chalcedony.

   The second locality of this mineralization type is represented by the occurrences in the area of Byšta – kúpele spa (Au, Ag + As, Sb) in the environment of crystalline rocks and in hydrothermally altered Neogene sediments. This occurrence is probably a lateral continuation of the mineralization at Füzérradvány in the Tokaj Mts.
5. Shallow steam-heated alteration zones with kaolinite ± alunite in the area of Pusté pole in the central zone of the Zlatá Baňa stratovolcano.
6. Small impregnations and stockworks of Hg mineralization (Hg + As ± Sb) are widespread in the Slanské vrchy Mts. The most important occurrence (exploited in the past) is at Dubník (by Červenica [Veresvágás]), in the peripheral part of the Zlatá Baňa stratovolcano. Cinnabar has very irregular distribution in the tectonically crushed and argillized andesite. Realgar is also associated to cinnabar.

2. Wines of the Tokaj-Hegyalja region

2.1 Introduction

The Tokaj wines rightly deserved their fame all around the world in the last 400 years. These wines belong to that group of wines that are strongly ruled by geological and other geofactors, in contrary of those other wines, which are dominated by viticultural and oenological technology or by the grape variety. For a brief description of the Tokaj-Hegyalja wine region see Nagymarosy in Rohály & Mészáros (2001, 2006), for more detailed informations see Alkonyi (2000), Rohály *et al.* (2003) and Botos & Marcinkó (2005). For those who are interested for constraints between wine quality and natural conditions, a short comprehension on the climatic factors influencing the wine-production can be read in Rohály *et al.* (2003), and on the geological factors in Rohály *et al.* (2004).

The most important geo-factors that influence the quality of the Tokaj wines are:

- geomorphology
- meso- and microclimate
- bedrocks
- soil quality
- cellars

2.2 Geographic position and short history of the Tokaj-Hegyalja wine region

The Tokaj-Hegyalja wine region lies on the southern and south-eastern slopes of the Tokaj Mts. According to a Latin proverb from 1803, the area of the Tokaj wine region "*incipit in Sátor and desinit in Sátor*", *i.e.* the wine region begins at the Sátor ("Tent") Hill at Abaújszántó, and ends at the Sátor ("Tent") Hill of Sátoraljaújhely, thus occupies territories along the southern and eastern parts of the Tokaj Mts. (Fig. 2).

After the proliferation of the name varieties referring to the wine region (*Tokaj, Tokaji, Tokay, Tockay, Tocay, Tocai*) during the centuries, the name was legally stipulated by the end of the 19th century. Since that time the first Hungarian wine-law (created in 1893) designated the wine region officially as *Tokaj-Hegyalja*. The word *Hegyalja* has been used already in the Medieval Latin as *regio submontanea* or *districtus submontaneus*. This word means "foothills" in Hungarian. The people actually living in the area refer to themselves as being not from Tokaj, but from the *Hegyalja*. The word "*Tokaji*" in the name of the Tokaj wine (the *-i* ending is a suffix indicating place of origin) refers to the region, where the wine happened to be grown (Roháły *et al.*, 2003).

The wine region potentially encompasses 11,149 hectares. Over the centuries, the area actually planted in Tokaj has been both larger and smaller than the 5,967 hectares under vines today. At this point, it seems unlikely that all of the 9,829 hectares rated Class I in the cadastre will ever be fully planted.

The total number of the classic wine producing settlements is 27 in Hungary and 2 more villages on the territory of Slovakia since 1919 (former Kistoronya and Szőlőske, now Malá Tŕňa and Viničky). In 2004 the Hungarian and Slovak governments agreed in the use of the Tokaj name in Slovakia. Under this agreement, wine produced on a special 5.65 km² in Slovakia has the right to use the *Tokaj* name. Unfortunately, the wine-law in Slovakia did not introduce the same very strict quality standards for the Tokaj wine as it is regulated in the Hungarian wine law since 1990.

The first known occurrence of the name, in the form of "Tokay", can be found in a 13th-century chronicle entitled *Gesta Hungarorum*, penned by an unknown chronicler referred to as Anonymus in Hungarian literary history. The *Gesta*, and many sources after it, refer to the emblematic hill of the region (*Tokaji-hegy, Tokaji Nagy-hegy, Kopasz-hegy*) not as Tokaj but as Tarcal, today the name of a village at the western foot of the hill. Remarkably, Tarcal was also the Hungarian name of the hill in Syrmia far to the south, today known as Fruška Gora in Serbia, which yielded the most famous wine of medieval Hungary (Rohály *et al.*, 2003).

In the 12th century, the immigration of Walloon or Italian settlers has been presumed in the Tokaj-Hegyalja region, although their viticultural influence cannot be proved. However, the true flourishing of the Tokaj wine started only in the late 16th century, when the Turkish Empire conquered half of Hungary and the Tokaj area has been annexed to the semi-independent Principality of Transylvania. The main markets for the Tokaj wine in this time were Poland, Germany and Austria. The princes of the Rákóczi family accumulated huge wealth and property (around ca. 1600–1660), among them large oppidiums planted by vines.

The profit from selling Tokaji Aszú wine helped in financial affairs to cover the costs of the war of independence against the Austrian rule. Ferenc Rákóczi II, the leader of the independence war has sent in 1703, to his ally, King Louis XIV of France a gift of numerous bottles of wine from his Tokaj estate. When it was served at the Versailles Court, Louis XIV declared it as "*Vinum Regum, Rex Vinorum*" ("Wine of Kings, King of Wines"). Maybe due to this slogan, the fame of the Tokaj wine increased very rapidly during the 18th century, and Tokaj reached the height of its prosperity. Even the Russian emperor maintained a winery in Tokaj in order to guarantee the supply of wine to the Russian Imperial Court, and so did the Austrian emperor as well. Several minor sovereigns from Germany had their private estates in Tokaj, too.

In the 19th century there was a slow but severe decrease in the exports of Tokaj wine and an economic decline of the region started. The phylloxera epidemic reached Tokaj in 1885 and destroyed the vast majority of the vineyards in a short time. Due to the Treaty of Trianon (1920), Tokaj wine lost its access to the majority of the domestic markets. Czechoslovakia gained an area of 120 hectares from the wine region.

The communist rule saw deterioration in the quality and reputation of Tokaj wines. Since 1990 a strict regulation of the quality of the Tokaj wine went on and significant amount of investments has gone into the Tokaj region, creating the so-called "Tokaj Renaissance". There are now nearly 600 wineries in Tokaj-Hegyalja. The region has been chosen among the World Heritage areas of the UNESCO.

2.3 Geomorphology

The volcanic cones of the Tokaj Mts. and Slanské vrchy Mts.[1] rise abruptly behind the escarpments, overlooking the mildly accentuated pediment surface and the floodplain of the Bodrog River. These days, the vineyards are confined to the southern, southwestern and eastern slopes in the foreland of the peaks, but there was a time when vines cultivated on terraces conquered the steepest faces, and reached the top of Tokaj Hill. The terrain in the viticultural zone is intensely articulated with valleys and streams.

As a consequence of the steep morphology, the area is highly vulnerable to soil erosion. On the other hand, the steep slopes (up to 30–35°) are the key-factors in the development of favourable microclimates.

The majority of the vine-planted area lies at a height of 120 to 250 metres above the sea level.

2.4 Climate

Meso-climate

The area is located near to the northernmost boundary of potential vine cultivation, between latitudes 21°10' and 21°40' N. Situated in northeastern Hungary, the Tokaj Range has a moderately cool ***mesoclimate***, which is a key factor in producing nice white wines with a proper acidity. The mean temperature at the foothills of the SW–NE directed range is around 9–10 °C (10.8 °C in average) annually, 21 °C in July, and –3 °C in January. The average temperature fluctuation is 13 °C annu-

[1] In Hungarian geological literature usually referred to as Eperjes–Tokaj Mts., Hungarian gegraphical literature incorrectly as Zemplén Mts.

ally, normally coupled with long, sunny summers and dry autumns also with a lot of sunshine. The total active amount of heat is between 1600 and 1800 °C varying in the respective terroirs among different geographical positions (Botos & Marcinkó, 2005). The yearly number of the sunny hours in the active vegetation period is more than 1400, but it is above 1500 in some years.

Precipitation measures between 500 and 700 millimeters in a year (525 mm in average, 313 mm in the vegetation periode), with an early-summer peak.

Microclimate and noble rot

The favorable south-southeastern dip of the foothills has contributed to the evolution of excellent ***microclimates*** on the slopes. The frosty cold air masses being dangerous for the grapes regularly arrive to Hungary from the North and Northwest. Therefore, the best vineyards – *terroirs* – occupy the southern slopes of the hills where they are sheltered from the northern and northwestern winds by relatively tall forested peaks. For optimum viticultural potential, these sites must have an outlet to the east or the west, as shut-in valleys have a limited circulation of air, and are more prone to stubborn frosts.

The cold air coming from the N and NW flows downslope due its high density and settles on the plain around the foothills. Thus, the average temperature of the slopes is usually higher than that of the surrounding plain.

Among dozens of superb vineyards meeting these criteria some very famous ones are the Szarvas, Hétszőlő and Nagyszőlő on the southern flank of Tokaj Hill (also known as Kopasz Hill, *i.e.* "Bald Hill"), the Disznókő and Király terroirs south of Mád, the Zsákosak, Omlás and Lőcse terroirs at Erdőbénye, the Mandolás and Gyapáros in Tolcsva, or the Meszes at Olaszliszka and the Oremus in Sátoraljaújhely (Alkonyi, 2000; Roháły *et al.*, 2003).

The microclimate is determined not only by the sunny, south-facing slopes but also by the proximity of the Tisza and Bodrog rivers. The high level of humidity multiplied by the intensive evaporation of the Bodrog and Tisza river confluence and the location in the lee, are the main causes of the development of a special fungoid flora in the air and on the skin of the grape-berries, including the all-important *Botrytis*.

The term *aszú* means berries or full grapes having a high sugar content and having been naturally desiccated and affected by the *Botrytis* (noble rot). The key of development of the so-called aszú grapes is due to the proliferation of *Botrytis* and the subsequent desiccation of the grapes. The grapes ripen are more fully, and when they are overripen the botrytis sets in under vapory conditions. Long and dry autumn is optimal for botrytisation, the noble rot penetrates the flesh of the fruit, where it transforms the aromas and it develops a relatively higher sugar content by extracting water. The famous Tokaj wine varieties are, therefore mostly wines crafted with the use of selected botrytis grapes (Eperjesi *et al.*, 1998).

2.5 Bedrocks

The vinestocks have a very long and deep root system, which penetrates not only the regolith on the surface, but it reaches also the basement rocks at a depth of several metres (Kozma, 1991; Wilson, 1998). According to measurements during a large area throughout the whole Tokaj-Hegyalja area, 10 years old vinestocks can reach a depth of about 1.6–1.8 metres in average (in hard substratum), while 40 year old plantations go as deep as 2.8–3.0 metres or more (Nagymarosy, 2004). This means that the effect of the basement rocks is much more substantial for the grapes (and thus for the wine) as the effect of the topsoil. This is why the Tokaj wines are so much influenced by the geologic conditions and this is the cause why different geological and other natural conditions of the different Tokaj terroirs produce vastly different wines. Of course, traditions, cultivation methods, grape varieties, and techniques of vinification can be also very important respecting the character of wine.

Tokaj-Hegyalja's terroirs are characterised mainly by a wide set of different volcanic rocks (Boczán *et al.*, 1966; Gyarmati *et al.*, 1976; Gyarmati, 1977; Fanet, 2004). The volcanic activity which began some 15 million years ago and dominated for about 6 million years, created a great diversity of formations and morphologies in the mountain range. The nearly full spectrum of volcanic rocks that can be found in the area includes rhyolite, rhyodacite, dacite, andesite (and in boreholes even basalt, which is much more typical of the wine-producing volcanic hills of Western Hungary). In addition to the lava formations, pyroclastic rocks, most significantly tuffs and ignimbrites, also occur in large quantities (Gyarmati, 1977). The Early Sarmatian rhyolite tuff yielded the famous fossil flora of Erdőbénye containing the oldest ancestors of the recent grape, the *Vitis tokajensis* and *Vitis teutonica* (Andreánszky, 1959; Főzy & Szente, 2007).

Although the individual members of one respective volcanic cycle differ from each other mainly in terms of silica content, but differ also in alkaline and phosphorus content. From point of view of wine production this latter two elements play a much more definite role in the metabolism of vines as silica. This is why the majority of the famous Tokaj terroirs is located upon one of the alkaline-rich rhyolite tuff horizons. In the North of the wine region the vine cultivation is focused on the Late Badenian rhyolite tuffs, while in the South the best terroirs are bound to the Early Sarmatian rhyolitic pyroclastics, or at a less extent to the Late Sarmatian ones. There are only a few terroirs which have dacites or andesites below their topsoil. (An interesting exception is the Palota terroir around Tolcsva. The basement rock is a dyke system here, full of jasper. This is probably the only place in the world, where vines grow upon a precious stone…)

Acidic pyroclastic rocks tend to weather faster than other igneous types, because of their high volcanic glass content. This is why the thickest and richest soils formed upon easily-weathered tuffs, while the soils above lava rocks are thinner, usually full of hard rock debris.

In addition to the natural surface weathering also post-volcanic processes altered the rocks. During and after the main paroxysms, a rich variety of postvolcanic activities left its stamp on the rocks of Tokaj enhancing their chemical alteration and weathering. These processes culminated in metasomatism, postvolcanic juvenile upwellings and hot springs, which delivered large quantities of alkalis (potassium and sodium) and other trace elements to the surface and thus enriched the volcanic detritus chemically. The major centers of postvolcanic alterations in the Tokaj-Hegyalja wine region are located in the area of Mád, Erdőbénye, Tolcsva, and Sárospatak.

The volcanism ended in the Early Pannonian. After a long periode of denudation aeolian loess deposited onto the southern fringes of the Tokaj range during the Quaternary. The loess deposits occur only around the Tokaj Hill, from Mezőzombor to Olaszliszka with more than 30 m thickness at some places. The loess is basically a fine sandy silt with significant clay content and it is quite rich in carbonate, too (7 to 20%). The loess is another important soil-forming rock of the region and the bedrock in some famous terroirs.

In terms of geology the wines of Tokaj can be subdivided into two large groups: "loess wines" and "volcanic wines". These types differ from each other both in their chemical composition and organoleptic characteristics.

2.6. Soils

The region's basic soil mantle developed during the Quaternary. On the steeper slopes, the thin soils are typically mixed with weathered lava rocks and are quite hard to till. In the low valleys and the foothills, redeposited soils of the slope, loam, and glacially disturbed soils occur. The weathered volcanic glass, also fragments of obsidian, pumice and perlite continues to mingle with the soils today, enriching them in trace elements and minerals.

In 1867, József Szabó, the "father of Hungarian geology" who provided the first comprehensive geological description of volcanic rocks, soils and their importance in the quality of the Tokaj wines (Szabó, 1867), distinguished three basic soil types, both in writing and on maps, from which all the other sub-types can be derived. The names of these soil types are not "scientific terms" but clearly describe the character of soils and are often used also among the workers in the vineyards.

The most widespread is the clayey *nyirok*, a red erubase soil created by weathering of volcanic rocks, particularly rhyolite and andesite, with a high occurrence of rock debris and rock inclusion (Ballenegger, 1917). In fact, this soil variety is an *andisoil* in terms of US soil classification. When too wet, *nyirok* gets so gluey that it sticks to the spade; if it dries out, it will yield to nothing short of a pickaxe. It does not absorb water very well and has low permeability. Its red color, from the ferric hydroxide, turns darker as its humus content increases. Yielding the most powerful and substantial wines in Tokaj, *nyirok* is the soil of the Király vineyard at Mád and Mezőzombor, the Meszes at Olaszliszka, and the Várhegy and Oremus at Sátoraljaújhely.

Of slightly lesser value is the soil type known as *yellow earth*, which forms from loess. The loess soils are confined to the southernmost part of the region. This soil variety is an *alfisoil* in terms of US soil classification. Its varieties in Tokaj are loess talus and loamy loess (both mixed with talus, debris and fossils), as well as sandy loess on the Tokaj Hill and the hills north of Olaszliszka. Loess has good water management, good drainage, and a low to medium lime content. The loess blanket of the foothills can be traced from Abaújszántó to Tokaj and from there to Bodrogkeresztúr. The Szarvas and Hétszőlő terroirs are famous examples of vineyards with loess soil. Loess does not crop up in the interior of the mountain chain or in the valleys, but on the southeastern slope of Tokaj Hill it can be found at altitudes as high as 405 meters.

The last basic soil type is the *rock flour* that forms from intensely silicified rocks and pumice. Basically, a lithosoil produced through mechanical weathering, rock flour is fine-grained debris of white rhyolite, pumice, and perlite. It is less coherent, not very malleable, and it does not retain water. Its heat capacity is inferior, so vines planted in it may easily get parched during a drought or freeze up in extreme cold periods. Rock flour is the soil type for example of the Pereshegy and Lócse terroir at Erdőbénye, the Tolcsva Hill, and the Oremus vineyard at Sátoraljaújhely.

2.7. Grape varieties

There are six officially approved grape varieties in Tokaj. Five of them are indigenous varieties occurring only in the Carpathian basin, the Yellow Muscat is a variety of French origin (Clarke & Rand, 2001):

- Furmint
- Hárslevelű
- Yellow Muscat (Hungarian: Sárgamuskotály)
- Zéta (previously called Oremus)
- Kövérszőlő
- Kabar

The two leading grape varieties in Tokaj-Hegyalja are the Furmint and Hárslevelű, often harvested, pressed, and fermented together throughout the region. This makes sense, as their time of ripening are quite close to each other, and many older plots still in cultivation are mixed plantations, containing the two varieties side by side. These two varieties cover 96–97% of the total cultivated area.

2.8. Tokaj wine types

The most famous wine of the region is the Aszú, blended with noble-rotten grapes, fermented and matured during the long so-called Aszú process. Its classical Latin name is *Vinum Passum Tokajense.* Distinct from this noble sweet category is the typically dry *ordinarium*, which is harvested *without* noble-rot grapes. *Főbor* ("principal wine") was the old name of Szamorodni-style wine, at least insofar as it was made by pressing the harvested fruit as is, *without separating botrytized berries from grapes unaffected by the noble rot*. From 1707 onward, Esszencia, the highest grade of Tokaji, was also increasingly referred to as *legfőbb bor*, meaning "supreme wine" (Rohály *et al.*, 2003; Botos & Marcinkó, 2005).

Nowadays, the wines of Tokaj are grouped and categorized in the following categories:

Dry wines:

- *Fresh or briefly matured wines.* Typically fermented dry but potentially containing some residual sugar (below semi-sweet category levels). With a few exceptions, they are fermented in stainless steel tanks. These are the wines for quick consumation. *Not* a classical style in Tokaj.
- *Matured dry wines (ordinarium).* Invariably matured in wood, with a small proportion also fermented in wooden casks. Very long lifetime and potential. As Botrytis is undesirable in these wines, the grapes must come from high-altitude vineyards (about 250 m above sea level) calibrated specifically for this purpose.
- *Dry Szamorodni (főbor).* Quality comparable to Beerenauslese, but fermented dry and subjected to subtle maturation (under a film of yeast). Contains botrytized grapes.

Sweet wines:

- *Sweet Szamorodni (főbor).* Typically made in the sweet style, when the sugar content of the grapes is so high that the must will not ferment fully dry. The residual sugar of Sweet Szamorodni is comparable to a 2 or 3 puttonyos Aszú, sometimes more. It needs to be matured for two or three years, and is lightly oxidized in character.
- *Reductive sweet wines.* Ready for release in a year or sixteen months after harvest, made in stainless stel tanks plus a short barrel aging. They may contain 50 to 180 g/l residual sugar and a ratio of botrytized berries comparable to Aszú wines. *Not* a classical Tokaj style, however very popular.
- *Aszú (3 to 6 puttonyos) and Aszúeszencia*
  Tokaji Aszú can be defined as a sweet wine with a high concentration of residual sugar that is made from hand-selected shriveled grapes affected by *Botrytis cinerea*, macerated in wine or must before pressing, and matured in oxidative conditions without adding spirits of a higher alcohol content. To our knowledge, no other wine available commercially in the world meets these manifold critera (Rohály *et al.*, 2003). At the same time, the Tokaj Aszú yields the highest level of acidity among all wines of Hungary.

Botrytis cinerea, a species of fungus causes noble rot, and it affects the fruit in two ways: by enhancing the evaporation of the water content from the berries, and by creating special aromatic substances inside. The noble rot infection does not occur each year. It is not exeptional but quite rare. According to statistics, aszú vintages used to occur in three years per decade on the average.

The aszú berries must be picked out of the bunches one by one, by hand during the harvest, thus selecting them from the non-botrytized grapes. After harvest, crushing of the grapes follows and the aszú berry pulp will be mixed either to the freshly pressed grape juice or to young dry wine. The unit of measurement of aszú-pulp is the *puttony* (butt) and for the juice a 136-liter cask (*gönci hordó, Gönc cask* – Gönc is a village in the heavily forested northeastern Tokaj Mts. and was the place of the traditional cask production) serves as a framework for measuring concentration. The grade of the Aszú depended on how many *puttony* (a 27-liter harvester's butt) of botrytized berries were blended with a 136 l caskful of dry wine or must. The more *puttony* aszú will be added the sweeter will be the wine.

The juice is poured on the aszú dough and left for 24–48 hours, stirred occasionally. The best growers reject the use of selected yeasts, preferring instead local wild yeasts naturally present in the vineyards to trigger fermentation. Then the wine gets into wooden casks or vats where fermentation is completed and the aszú wine starts to mature. The casks are stored in a cool cellar. They are not tightly closed, so a slow fermentation process continues in the cask, usually for several years.

The different aszú wines must contain a minimum amount of sugar by law. The increasing number of puttonys means an increasing sugar concentration. Table 2 shows minimum residual sugar and extract required per grade.

The Esszencia *(legfőbb bor)* is the sweetest wine of the region. The free-run juice of hand-picked pure botrytis berries accumulates, with over 450 g/l sugar (but levels of 800 g/l or more are not unheard of). Esszencia takes years to achieve a modest alcohol level of 4-5%.

Table 2. Residual sugar and sugar-free extract contents of Aszú wines

Wine type	*Residual sugar (g/l)*	*Sugar-free extract (g/l)*
3 puttonyos / 3-butt Aszú	60	25
4 puttonyos / 4-butt Aszú	90	30
5 puttonyos / 5-butt Aszú	120	35
6 puttonyos / 6-butt Aszú	150	40
Aszúeszencia / Aszú essence	180	45

Among other factors, high acidity makes a fundamental contribution to the unique character of Tokaj wines, particularly to Aszú. Having high concentration of sugar the malic acid is never a problem, but the wine will have high levels of other, more benign acids that keep the often extraordinary sweetness from being cloying. Working in a synergistic combination with the acids, these substances can attain a perfect balance with the intense sweetness of Tokaji Aszú (Rohály & Mészáros, 2001, 2006).

The mineral and trace elements, present in the soils of Tokaj in a form that is readily accessible for the vine's roots, contribute their own flavors to the wines. This is the typical *"mineral taste"*. Due to the diversity of terroirs in the region, the wines show distinct features observable by organoleptic analysis. Wines having harvested from loess soils are less mineralic in taste, than those of volcanic soils. Different volcanic sub-soils can lend either salty taste to the wines (high level of sodium and potassium), or represent a slightly bitter palate on other terroirs (magenesium-dominated wines). Generally, wines from volcanic soils usually have a pronounced mineral taste.

Micro-oxidation in a wooden cask is a further key factor in making good Aszú or another Tokaj wine type. Micro-oxidation, which essentially occurs through the pores in the barrel's wood, is certainly not amenable to making wines that will seem 10-20 years old at three to four years of age; this can be achieved, if it must, by not topping off barrels and by frequent racking. Tokaj wines handled this way will develop rich tertiary aromas and flavors, without losing their acidity and mineral taste unmatched by any other sweet wine in the world.

2.9. Cellar

The wine cellar systems in Tokaj-Hegyalja are the most-extended ones in Hungary and also in Europe. Such a vast building system constructed exclusively for wine production is unique in the whole world. The sum of the length of the cellars in Tokaj-Hegyalja is unknown, but according to some estimations they reach a total of 20,000 kms (Laposa & Dékány, 1999).

About 98% of the region's sweet wines are aged in 4-5 meter wide single-vaulted cellars. They are sometimes two or three-levelled buildings. These cellars have a constant temperature of 9–11 C°, depending on their depth below the ground and other circumstances, but are never subject to fluctuations over the year.

The substratum of the cellars is usually one of the rhyolitic tuff horizons, except for the surroundings of the Tokaj Hill, where all of the cellars are carved into loess. The rhyolitic tuff cellars provide optimal conditions for maturing and storing wines. The non-permeable rhyolite tuff gives total isolation against humidity and subterranean waters. The cellars fix a stable temperature around 9 to 11° C, which is ideal for the aging of wines.

Even more important are the adequately high and constant levels of atmosphaeric humidity, owing to the presence of the black mould called *Cladosporium cellare* that clings to the cellar walls. Pleasantly warm and dry to the touch, this fungus performs a vital function in the cellar by acting as a humidity buffer (Rohály *et al.*, 2003), fixing the value of humidity between 60–70%.

3. Field stops

3.1 Field stop 1. Perlite quarry at Pálháza, Tokaj Mts., Hungary (F.M.)

The Tokaj Mts. is a rather unique area within the Carpathian Volcanic Arc considering the volume of rhyolitic rocks. The Tokaj Mts. consist of two large rhyolitic volcanic fields, each of them cover more than 100 km^2 area. One of therm is located in the southern part of the mountains between villages of Erdőbénye, Mád, Szerencs and Abaújszántó, whereas the other large rhyolitic field is located in the northern part of the mountains, between villages of Telkibánya and Pálháza (Fig. 2). The most typical K-Ar ages for the southern rhyolite field are around 11 Ma, whereas rhyolite appears to be older with most common K-Ar ages around 12-13 Ma in the northern field. Rhyolite occurs mostly in terrestrial dome-flow complexes in the southern Tokaj Mts., whereas the northern rhyolite field also contains subaqueous dome, cryptodome, hyaloclastite breccia and lava flow complexes.

An economically important feature of the northern rhyolite field of the Tokaj Mts. is the common occurrence of perlitic rocks. Perlite is a valuable raw material due to its expansion during heat treatment. The perlitic rhyolite glass contains up to 5 wt% H_2O. Heating up grinded perlite to about 700 °C causes partial melting (temperature of this process depends on K and Na contents) and releasing of structurally bonded water from the volcanic glass particles: this process – like making popcorn – blows up the semi-molten glass fragments into particles with extremely high specific volume. Expandability of perlite is between 1:10 and 1:20 depending on the composition of the material and also the heat and duration of treatment. The expanded perlite has high absorption capacity and therefore can be used for filtering chemicals and blotting of oil pollution from water. Modern building industries use expanded perlite for preparation of light concrete blocks due to their excellent heat insulation and soundproofing properties. Agriculture also uses expanded perlite for soil treatment. Hungary is among the top perlite producers of the world and almost all of the perlite production of the country is from the quarry at Pálháza owned by the Perlit '92 Ltd.

The quarry on the Gyöngykő Hill (*i. e.* "Pearlstone Hill") exposes a part of a subaqueous rhyolite intrusive and extrusive

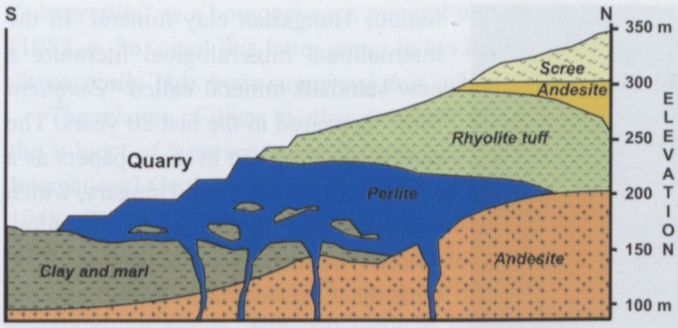


Fig. 6. Simplified geological section of the perlite deposit at Pálháza, Tokaj Mts.

dome-flow complex in a more than 200 m thick section above the Lower Sarmatian andesite and marine sediments (Fig. 6). According to Németh *et al.* (2008) the section represents coherent submarine cryptodomes sourronded by hyaloclastite breccias with local occurrences of peperitic facies around intrusives (Fig. 7).

The lower part of the section exposed in the quarry of the Gyöngykő Hill reveals that the rhyolitic cryptodomes and endogeneous lava domes partially intruded into the wet unconsolidated pelitic sediment and thus jigsaw-fit breccia zone containing mixed igneous and sedimentary material (peperite facies) developped along these contacts (Figs. 8a and 8b). The contact of the magmatic bodies to the underlying sediments is highly irregular and undulates over tens of metres. The proportion of marine sediments in the breccias increases with distance from the rhyolite body. Muddy sedimentary dykes also penetrate into the jigsaw-fit breccia zones. In the lower levels of the sequence, boudinage-like sedimentary clast-trains up to 5 m in length are common. The deformed sedimentary clasts are both compressed and sheared to form highly irregular-shaped lensoid or flame-like megastructures.

Up-section the magmatic bodies are more coherent but laterally pass into fragmented volcanic rocks (Fig. 7). Branches of coherent cryptodomes form "cauliflower-like" complex bodies; the individual cryptodomes are lensoid-mushroom shaped with several tens of metres thickness and extension. Columnar jointing (Fig. 8c) and flow-banding is typical for the inner part of domes and some of the flow bands built up by obsidian. In general, the texture of rhyolite is porphyritic (K-feldspar, quartz, biotite), aphanitic and vitriclastic. The unevenly distributed perlitisation characterizes even the inner parts of the domes, however, it is more pronounced towards their fragmented margins, where vesiculation is also more common. Perlitisation is also characteristic to the volcanoclastic units.

The fragmented caps of the cryptodomes consists of monomict breccias which are interpreted as their autoclastic carapaces, however, laterally they grade outward into jigsaw-fit, hyaloclastite breccia (Figs. 7 and 8d). This breccia is rich in glass shards with ash-grade matrix-supported texture. Hyaloclastite domains are locally also present within the flowbanded coherent rhyolite bodies. The hyaloclastite breccias are finer grained with increasing distance from the contact with the coherent

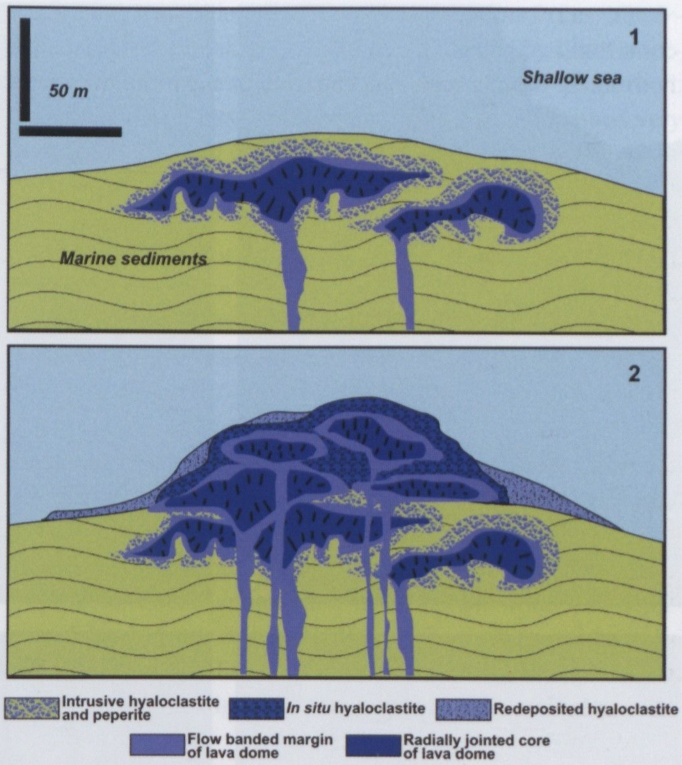


Fig. 7. Evolution of the intrusive-extrusive rhyolite cryptodome complex at Pálháza, Tokaj Mts. (modified after Németh *et al.*, 2008).

rhyolitic units. Clasts in both the matrix-poor and -rich breccias range between 1 cm and up to 2 m. The fragments are generally angular, and show glassy textures with common flow-banding enhanced by alternation of perlitic and obsidian bands up to 2 cm thick. The hyaloclastite breccia mantle of the domes reach up to 100 m width and weak bedding appears away from the coherent magmatic bodies. Fine-grained volcanoclastic "tuff" also forms the cover of the cryptodomes (Figs. 6 and 7). The uppermost part of the volcaniclastic succession also contains large, plastically deformed, slightly thermally altered mud clasts up to 10 m in diameter.

In summary, the volcanological characteristics observed in the section exposed in the Gyöngykő Hill reveals that rhyolite intrusions invaded and partially encapsulated marine mud, forming peperite along the contact. The low-volume, but sustained and pulsatory magma supply led to the unsteady growth of a network of several cryptodomes which broke through the sedimentary cover to form a lava dome complex with an associated hyaloclastite pile around the network of feeder zones (Fig. 7).

The chemical composition of the perlitic rhyolite is as follows: SiO_2 68–75%; Al_2O_3 10–15%; Fe_2O_3 1,0–2,5%; CaO 1,5–2,0%; MgO 0,2–1,5%; K_2O 3,2–4,5%; Na_2O 2,8–4,5%; LOI 2,0–5,0%. There is no significant chemical difference between strongly perlitic and less perlitic rhyolite except of H_2O and Cl contents (Németh *et al.*, 2008). Rhyolite contains 1.4 wt% H_2O only, and the Cl content (460 ppm) is also lower than it is for perlitic rhyolite (676–740 ppm). The darker perlite shows slightly higher H_2O and Cl content that the light one.

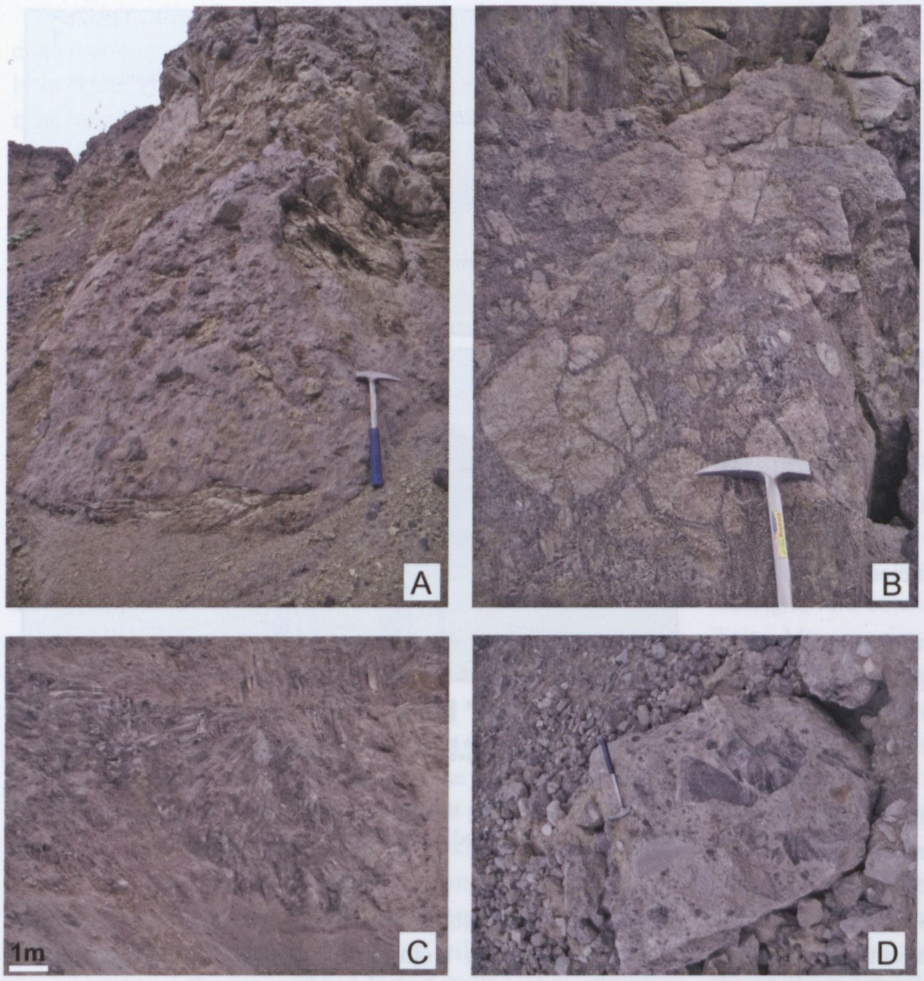


Fig. 8. Facies of the rhyolitic dome-cryptodome complex at Pálháza.
a – contact zone of argillic sediments and a rhyolite intrusion; b – peperite at the contact between rhyolite and sediments; c – radially jointed core of a rhyolite dome; d – hyaloclastite breccia.

K-Ar ages for the perlitic rhyolite are between 13.37 and 13.94 Ma (±0.4 Ma). The K-Ar ages are also concordant with the biostratigraphic Lower Sarmatian age for the sediments (Pantó 1966b, 1968; Székyné Fux *et al.*, 1981) mixed with the volcanic material.

3.2 Field stop 2. Illite mine at Füzérradvány, Tokaj Mts., Hungary (F.M.)

3.2.1 History of mineralogical investigations and current state of knowledge about illite of the Füzérradvány locality

The Korom Hill in the vicinity of Füzérradvány village is situated in the north-eastern part of the Tokaj Mts. and 18 km northwest of the town of Sátoraljaújhely (Figs. 1 and 9). The recognition and exploitation of the ceramic clay locality of Korom Hill at Füzérradvány (Tokaj Mts.) dates back to the first half of the 19th century. In the 1930s the material became famous as one of the first known occurrences of micaceous clay minerals. The *Füzérradvány "illite"* was first described by Maegdefrau & Hofmann (1937) who compared their results on the *"mica of Sárospatak"* with those of a *"sericite-like mineral"* from Illinois, U. S. A., the material that was named *"illite"* by Grim *et al.* (1937), and found considerable similarities. Thus the *"mica of Sárospatak" (i.e. Füzérradvány "illite")* has a very close relation to the birth of the widely used mineralogical term "*illite*". Since this time the material was subject of numerous investigations. By these studies the *Füzérradvány "illite"* became probably the most famous Hungarian clay mineral. In the international mineralogical literature a new standard mineral called "*Zempleni illite*" appeared in the last 20 years. The sample is described in those papers as a hydrothermal clay from Hungary, which was provided by J. Środoń (Srodon, 1984). The identity of "*Zempleni illite*" with the *Füzérradvány "illite"* and the main results of its recent investigations were discussed by Viczián (1996, 1997). The name "Zempleni" refers to a geographic region: Zemplén is the name of a historical county and today the name used by the Hungarian geographical and touristic literature to the mountain range that includes the locality Füzérradvány, *i.e.* a synonym of Tokaj Mts (preferred usage in the Hugnarian geological literature). The same expression occurs in the name of the Zemplín Hills, a Palaeo-Mesozoic structural unit on Slovak territory, in a few kilometres distance east of Füzérradvány. The history of studies and current mineralogical knowledge about the "*Zempleni illite*" is summarized below on the basis of a papers published by Viczián (1996, 1997), see also Papp (2004).

Maegdefrau & Hoffman (1937) carried out X-ray diffraction investigations using X-ray camera and photometric registration on the "*mica of Sárospatak*". Their X-ray pattern clearly shows the series of basal reflections at 10,09 Å etc. which were indexed as 002, 004, 006 and several *hk0* reflections and the reflection 060. On the basis of the X-ray pattern they stated that the material has a muscovite-like structure. They also observed that there are only 1.41 K (Na, Ca) cations instead of the possible 2 per formula unit and supposed that the rest of sites is occupied by water molecules. The thermal decomposition was determined by subsequent heating and most of "constitutional water" was lost in the interval 400 to 500 °C. In addition, the optical index of refraction, base exchange capacity and the fraction <2 µm were also determined. Later on, Maegdefrau (1941) proposed the mineral name "*sarospatite*" and Hofmann *et al.* (1943) defended the identity of the micaceous clay mineral "*sarospatite*" as a homogeneous mineral phase and then Grim (1953, p. 36) cited this latter paper in his book and wrote that *"sarospatite"* has been suggested as a substitute for illite.

The relation of illites to other phases of similar structure was the subject of a presentation of Grim and Bradley in the 18th International Geological Congress in London (Grim & Bradley, 1948). Those illites that we would call today "discrete" phases were opposed to the "mixed-layer crystallizations" and *"sarospatite"* was considered to be example of mixed-layers of illite and montmorillonite. This way Grim & Bradley (1948, 1952) recognised the first time the mixed-layer nature of *"sarospatite"*.

Kiss & Takáts (1963) carried out detailed mineralogical studies including X-ray diffraction analysis on the *Füzérradvány "illite"* but the main goal was to test the material as fine ceramic raw material from technological point of view. They observed thermal loss of OH at temperatures typical both for *illites* (550–600 °C) and for *montmorillonites* (700 °C). The idea of Grim & Bradley (1948) about the mixed-layer character of the mineral was discussed but finally it was rejected.

More detailed description of the mineralogy of *Füzérradvány "illite"* was given by Nemecz & Varju (1970). The basic mineralogical properties were determined using X-ray diffractometric, thermal and chemical methods. It was shown that the composition varies from sample to sample. Nemecz recognised the *interstratified nature* of the material and estimated the proportion of the expandable layers in the range of <10% to 26% using the Hendricks–Teller formula. The *d* value of the basal reflection 001 varied between 10.14 Å and 11.05 Å, accordingly and also the split of the 001 reflection upon ethylene glycol treatment varied.

Nemecz mentioned the Füzérradvány "illite" several times in his book "Clay Minerals" (in Hungarian: 1973, in English: 1981, pp. 336–343 and 464–469). He recognised the 1*M* polytypic modification, and published thermal curves and TEM photographs about the mineral.

The mixed-layer nature of the material was more precisely determined by X-ray diffraction by Szegedi (1988). She used the direct Fourier transform method and the graphs published by Środoń (1980) and found the proportion of the expandable layers in one of the samples to be in the range 10–13% and the ordering of ISII type.

The first electron micrographs of *"sarospatite"* were made by Hofmann *et al.* (1941). The name *"sarospatakite"* occurs in the electron microscopy atlas of Beutelspacher and van der Marel (1968). In the description, they list *"sarospatakite"* among "mica minerals" and stress the "perfectly crystallized thin plates and laths" and "excellent crystallization properties" of the mineral. The locality, however, is somewhat erroneously given as "Nagybörzsony, Sarospatak, Hungary". The lath-like particles of the Füzérradvány material are also included into the electron microscopy atlas of Henning & Störr (1986). The mineral is called here *"illite of Füzerradvany (sarospatakite)"*, which they consider as "a morphological exception" among "irregular montmorillonite-muscovite mixed layer minerals".

Środoń (1984) described the *"Zempleni illite"* (i.e. *"Füzérradvány illite"*) as an illitic material dominated by illite/ smectite with ISII ordering and S = 17% smectite proportion. Further investigators observed R3 ordering and obtained very similar figures for S = 18% (Ahn & Buseck 1990), 17% (Veblen *et al.*, 1990), 14% (Reynolds 1992), 16% (Środoń *et al.*, 1992), by XRD method.

Some doubts arose concerning the mixed-layer nature of the *Füzérradvány "illite"* by the application of the HRTEM technique. Dódony (1985) observed stacks of several mica (muscovite) layers. These stacks were rotated on their 001 plane in respect to each other. On the basis of these observations and one dimensional electron density calculations Dódony (1985) denied the existence of interstratification in the Füzérradvány illite. This opinion was also supported by Patzkó & Szántó (1983), who observed by peptisation methods that the finest fraction contained only pure illite without interstratifications.

The chemical composition of *Zempleni illite* was determined by Veblen *et al.* (1990), using electron microprobe analysis (Table 3). The NH_4 content was checked by Środoń *et al.* (1992) and no significant amount of NH_4 was found.

Table 3. Composition of illite from the Füzérradvány clay deposit, Tokaj Mts. (from electron microprobe analyses, Veblen *et al.*, 1990).

Chemical composition (wt%)	
SiO_2	47.29
Al_2O_3	29.58
TiO_2	0.07
FeO	0.10
MgO	1.95
MnO	0.02
CaO	0.66
Na_2O	0.00
K_2O	7.67
Total	87.34
Structural formula (for 11 oxygens):	
Si	3.34
Al^{IV}	0.66
R^{IV}	4.00
Al^{VI}	1.81
Ti	0.00
Fe	0.01
Mg	0.21
Mn	0.00
R^{VI}	2.03
Ca	0.05
Na	0.00
K	0.69
Interlayer *R*	0.74
Σ_{cat}	6.77

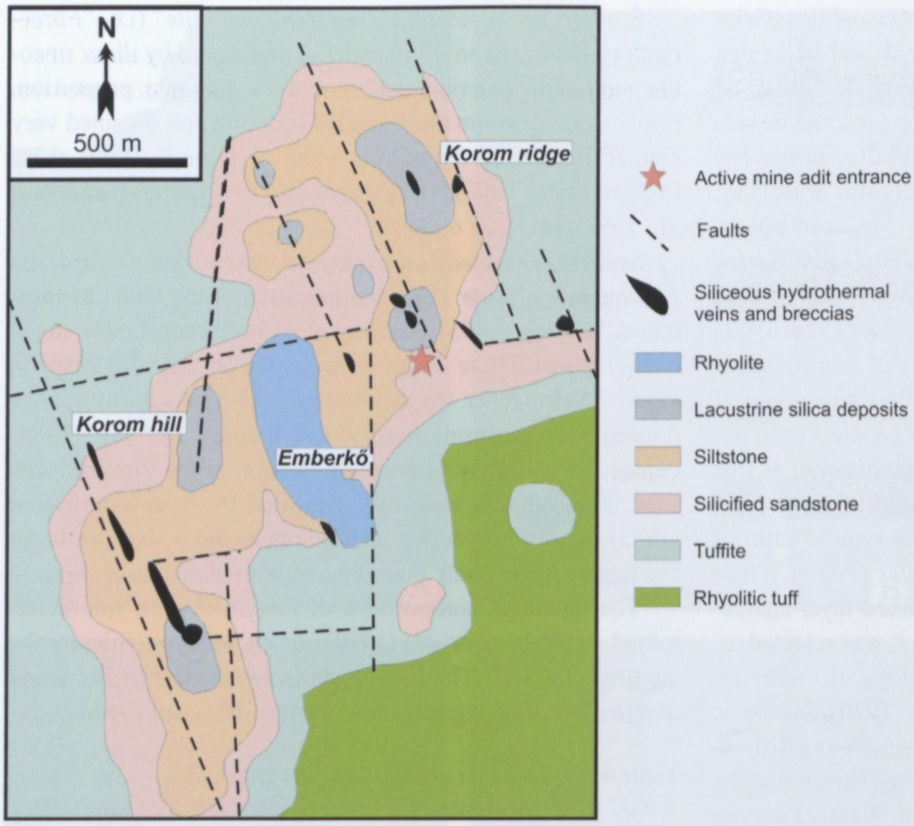


Fig. 9. Geology of the Korom Hill and Emberkő Hill area at Füzérradvány, Tokaj Mts. (modified after Pécskay *et al.*, 2004).

HRTEM images obtained by Ahn & Buseck (1990) indicated regions with coherent stacking and 1*M* polytypic order interrupted by stacking faults in the *"Zempleni illite"*. The resulting modification as seen by XRD is dominantly $1M_d$ with missing, weak or broadened *hkl* reflections. The thickness of the coherent packets is exceptionally high, that of 8 or more illite layers. The projected stacking vectors of the illite layers are tilted in the same direction within the packets, however their angles differ slightly indicating variations of the β values of individual layers. The occurrence of relatively thick stacks in the structure of *"Zempleni illite"* explains why typical 1*M hkl* reflections are clearly visible on its X-ray diffraction patterns.

The *"Zempleni illite"* was selected for TEM study by Veblen *et al.* (1990) as typical material for the R>1 ordering type of mixed-layer illite/smectites. They presented TEM micrograph, in which characteristic chaotic intergrowth, porosity, and bending of elongated lath-like crystallites are shown. Electron diffraction images have shown 40 Å periodicity parallel to c* and indicated …ISII-ISII… type ordering. Packets consisting of 2-6 illite layers were separated by one smectite layer (Fig. 10). The frequency of the smectite interlayers was counted in the HRTEM micrographs and the proportion of smectite layers S = 25% was computed. This is in good agreement with the value obtained by XRD (S = 17%). Similar comparison of the S % values obtained by counting on electron micrographs and by XRD method was carried out on several standard illite/ smectite materials including the *"Zempleni illite"* by Środoń *et al.* (1992). They obtained maximal S values 32% using TEM micrographs and 21% using HRTEM images, while S = 16% was determined by XRD. The difference was explained by different degree of dispersion during sample separation. Particles were maximally dispersed for the TEM analysis and less dispersed for X-ray analysis. The coherently scattered domains contained not only illite layers but also a few smectite layers.

3.2.2 Geology and origin of the illite deposit at Füzérradvány

In the area of Füzérradvány, the basement of the Tokaj Mts. is represented by a sequence of gneiss, amphibolite and mica schist of Paleozoic age. These metamorphic basement rocks are exposed east of the Korom Hill, both in Hungary and in Slovakia (Fig. 2). Based on drillhole data, the basement rocks are overlain by Miocene (Badenian) sediments.

The area of Korom Hill represents a tectonically uplifted block in which the oldest exposed rocks are marine clays of Upper Miocene (Sarmatian) age overlain by ignimbrite (pumiceous rhyolitic tuff) and tuffite (Figs. 9 and 11). A lacustrine sequence of about 100 m thickness forms the cover of the acidic volcano-sedimentary units (Mátyás, 1974; Gyarmati, 1977). Most of the lacustrine sediments consist of siliceous rocks partly due to the sedimentation environment of high silica content and partly due to the superimposing hydrothermal alteration. The main rock types of this lacustrine sequence are silicified fine-grained sandstone and silicified siltstone with fossil plants and molluscs. Lacustrine silica of white, black and red colour occurs at the top of the sequence. The lacustrine silica beds were deposited in small lakes fed by hot springs: the major outflow zones are characterized by opal-chalcedony moulds of a few tens of meters diameter. The above described sequence is penetrated by a rhyolite extrusion now exposed with 200 m by 700 m aerial extension on the Emberkő Hill (Fig. 9).

All of the above mentioned rock types are cut by siliceous hydrothermal breccias and quartz veins (Fig. 9). Breccias appear to be the youngest hydrothermal features because they contain fragments of quartz veins. Quartz veins have microcrystalline massive or occasionally banded appearance. Thickness of subvertical veins is from 0.1 m (quartz veins) to up to 20 m (breccia veins) with predominantly northwest–southeast orientation. The orientation of veins corresponds to the most common direction of faults in the

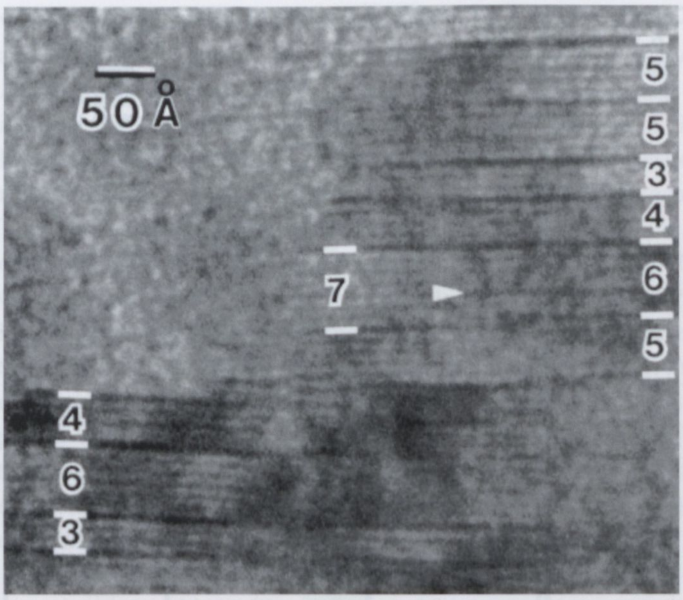


Fig. 10. HRTEM image of layer sequences in "Zempléni illite" sample showing variable thickness of illite stacks between smectite interlayers represented by dark fringes (Veblen *et al.*, 1990, Fig. 6).

mineralized area, however, east–west and north–south trending unmineralized faults also occur.

In the area of the Korom Hill, lithogeochemical and soil sampling revealed geochemical anomalies of Au, As, Sb and Hg (Hartikainen *et al.*, 1992). Hydrothermal activity and mineralization is clearly confined to the northwesterly striking strongly silicified zones of 10 to 50 m diameter width sitting along fault zones. Silicification and alteration is known in an area of about 10 km^2 and extend to the Early Paleozoic crystalline basement units. Mineralization in the basement represents a deeper level, possibly a feeder zone of the same system.

Current mineral exploration program by the Carpathian Gold Ltd. found several zones with high concentrations of silver and promisiong gold concentration values in drillholes that cut siliceous zones and quartz veins.

The formation of the illite deposit at Füzérradvány can be confined to the shallow zones of hydrothermal activity developed in the ignimbrite and tuff units and lacustrine sedimentary sequence of the Korom Hill. Illite occurs in the hydrothermal alteration zone along the major siliceous veins forming the feeder zones of the shallow plaeo-hot spring environment (Fig. 11). In the vicinity of the hydrothermal vents, silicification and kaolinite alteration occur proving the acidic, silica-rich nature of hydrothermal fluids. Silica content of these fluids caused intense silicification of clastic sediments and deposition of siliceous layers in the covering lacustrine-sedimentary sequence. The lacustrine environment also supported syngenetic precipitation of clays in periods of restricted transport of terrigeneous materials. Neutralization of hydrothermal fluids during interaction with rhyolitic tuff units at depth resulted in illitization further away from the hydrothermal vents. These illite-rich zones form the area of recent exploitation. Towards the marginal zones of the hydrothermal alteration smectite and less altered rock units can be found.

The mineable illite pods are up to 10 m thick and are outlined by the K_2O content of the altered ignimbrite and rhyolitic tuff and tuffite and high values reflect almost pure illite composition (Fig. 12). Excess potassium content probably reflects association of hydrothermal K-feldspar (adularia) with illite. The high-quality pure industrial illitic material has almost the same composition as the *"Zempleni illite"* (Table 3).

Geology of the clay deposit at Füzérradvány indicates that a volcanic and sedimentary sequence was cut by hydrothermal

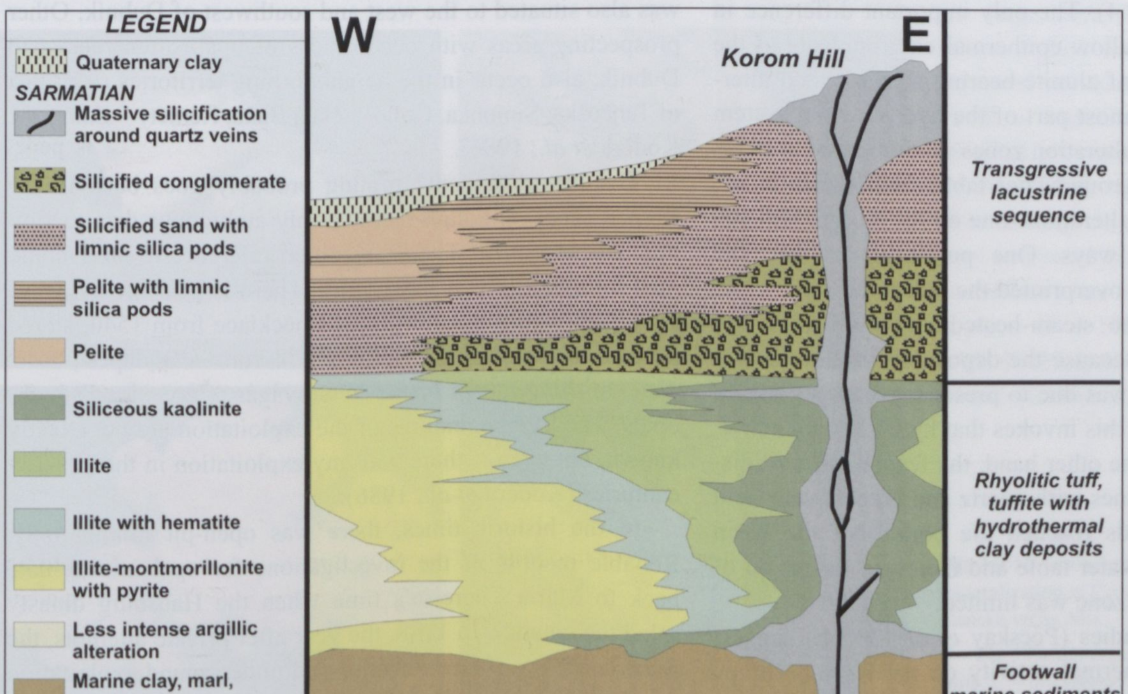
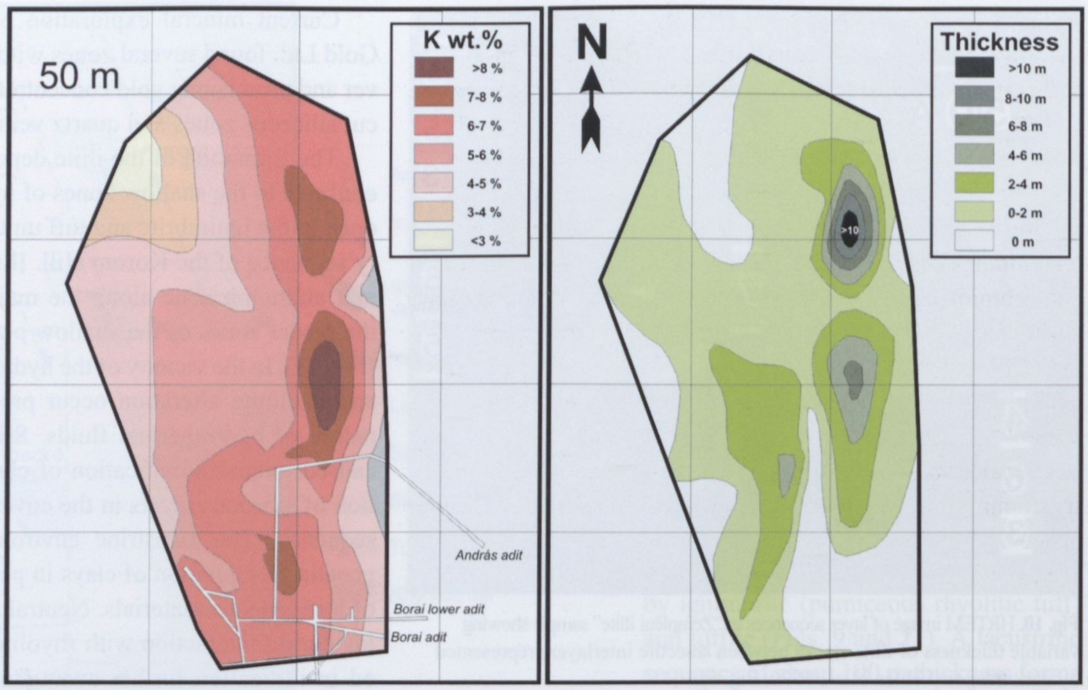


Fig. 11. Idealised section with zoning of hydrothermal alteration in the illite deposit at Füzérradvány, Tokaj Mts. (modified after Pécskay *et al.*, 2004).

Fig. 12. Distribution of the K_2O contents and thickness of mineable illite bodies at Füzérradvány, Tokaj Mts. (after Mátyás, 1972 and 1979b).



vents and argillic alteration zones are centred on those vents (Fig. 11). The relatively acidic nature of fluids in the main channels is expressed by the occurrence of kaolinite along the veins. Illite forms in less acidic conditions in epithermal systems (Hedenquist *et al.*, 1996). Thus illite occurrence in certain zones apart from the main hydrothermal channels can be explained by neutralization of acidic hydrothermal fluids during their interaction with permeable rock units. The overall zoning of hydrothermal alteration on the Korom Hill is very similar to that of other mineral deposits of the Tokaj Mts. (Mátyás, 1972) and corresponds to shallow levels of low sulphidation type epithermal systems (Molnár, 1994; Molnár *et al.*, 1999; see also Fig. 4). The only important difference in comparison to other shallow epithermal environments of the Tokaj Mts. is the lack of alunite-bearing steam-heated alteration zone in the uppermost part of the hydrothermal system (Fig. 4). Steam-heated alteration zones in epithermal systems form above the palaeogroundwater table (Hedenquist *et al.*, 1996). The lack of this alteration zone on the Korom Hill can be explained by two ways. One possibility is that the hydrothermal alteration overprinted the lacustrine-sedimentary environment and the steam-heated alteration zone has already eroded away. Because the deposition of silica in the lacustrine environment was due to presence of hot springs in the sedimentary basins, this invokes that hydrothermal activity had two stages. On the other hand, the feeder zones of discharges might be the zones with quartz and breccia veins and thus hydrothermal fluids reached the bottom of the basin under the paleogroundwater table and therefore formation of steam-heated alteration zone was limited.

Results of K-Ar studies (Pécskay *et al.*, 2006b) suggest that age of the hydrothermal activity on the Korom Hill is 11.89 ± 0.3 Ma.

3.3 Field stop 3. The Dubník–Libanka precious opal deposit at Červenica, Slanské vrchy Mts., Slovakia (S.J. and P.B.)

3.3.1 History of mining

The famous precious opal deposit of Červenica (former Veresvágás) occurs in the surroundings of the small village Dubník, in the Slanské vrchy Mts. (Fig. 5). The recent exploitation of precious opal took place especially in the foothills called Libanka (west of the road from Červenica to Dubník, approximately 3-km north from Červenica. A smaller mining district was also situated to the west and southwest of Dubník. Other prospecting areas with occurrences of opal, often related to Dubník, also occur in the neighbourhing territories (*e.g.* area of Tancoška, Šimonka, Čollo – Zlatá Baňa, Remety – Zámutov; Koděra *et al.*, 1986).

The history of opal mining probably goes back to the Roman times, although there is only ambiguous data to support this argument. The first written reference to the Dubník opal mines is known from 1597. There is possible evidence from older times: Queen Isabel's necklace from 1540, stored in the collections of the National Museum in Budapest, bears distinguishing marks of the Versesvágás (Červenica-Dubník) opals. The true beginnings of the exploitation are not exactly known, not even if there was any exploitation in the 11^{th}-12^{th} centuries (Koděra *et al.*, 1986).

In the historic times, there was open-pit mining only. Reliable records of the investigations for opal mining date back to Maria Theresia's time when the Habsburg dinasty ruled the country. In 1788, the year after private attempts, the mine became a state enterprise and underground exploitation was established. Systematic prospecting started and mining works were carried out in the second half and towards the end of the 18 century. At this stage, the opal from Dubník dominated the world market of precious opal. From the beginning of the 19th century, mine workings were gradually hired out. The most famous period for the Dubník opal minings began in 1803. In 1845, the Goldschmidt family became the tenant. During their 35-year-long mining operation, the biggest boom in precious opal exploitation took place. The following period was characterised by a tendency to rationalise the operations and the security of mining permanently became more difficult (Koděra *et al.*, 1986).

Around the turn of the 19th and 20th centuries, competition with precious opals from Australia started arose and prices decreased. In 1896, the opal mines went under the state control of the Kingdom Hungary. The most alarming question was the use of opals, because there was no demand and also business contacts were being lost. From the year 1911, mining production was still decreasing. After World War I opal mines went under the state control of the Czechoslovak Republic. After that, the French company Bittner – Belangenay hired the opal mines (Butkovič, 1970). At the end of 1922, mining completely stopped. In the last few years, the firm Savarna (Slovak opal) obtained the productive area of the deposit. Later it was taken over by Opal mines Dubník a.s. Červenica, and from 2005 to 2008 Opal Minings and Grindery s.r.o. Prešov. However, one part of this mining claim was declared as a protected area, called "Dubník Mines", in 1964.

The centre of the opal mining area was the village Dubník, where the administrative centre was established at the end of the 18th century. From 1880 to 1918 the mining fields on Libanka were united, and the total area of the mining property was 361,474 m^2. 14 main adits (Karol, Leština, Ján, Bučina, Baska, Apolónia, Paulína, Močiar, Fridrich, Ľudovít, Richard, Emília, Jozef, Viliam) were opened there. The whole length was 7–10 km with an altitude difference of 114 to 135 m. When the deposit was first exploited, the known mineralized zone was 1350 m long. More information about other mining districts has not been retained. Documents about the flourishing opal exploitation and mining have been preserved and the area of Libanka, that was one of the best deposits, is partially accessible today. The slopes of Libanka are still covered with the holes of abandoned adits, pits, pings, cuts and dumps (Repčiak, 2005).

The total quantity of extracted raw material is unknown. The estimated extracted amount of opal bearing rock in Libanka is 1.5 millions m^3. During the second half of the 19th century, approximately 20,000 to 30,000 carats per year were extracted. From 1897 to 1900, the extraction was only 2177 to 6853 carats/year, and from 1901–1907 it was 2160 carats/year only. From 1908 to 1918, 769 to 4742 carats/year were obtained, and in the last years of mining, from 1919–1921, the production was only 3705 carats/year. The average weight of precious opals from the Dubník grinderies was about 1 carat.

The largest specimen of precious opal from the Dubník area that has ever been found is the "Harlequin" or, "Vienna Imperial Opal" with 594 g (2970 carat) weight (Fig. 13a), now exhibited in the Natural History Museum, Vienna, Austria. The exact place and time of its finding is unknown, it is generally thought to be carried from Hungary to Vienna during the reign (1740–1780) of Maria Theresa but there is a report from 1673 about a fist-sized rough opal seen in the rarity collection of the Vienna Imperial Court. The current estimated value of this opal is about 500,000 US dollars. Other large pieces were found in 1868: their weight was 160 carats after trimming and polishing. The largest opal nest (called Gizelina chapel) was found in 1889 in the Viliam adit, and was about 75×50×30 cm large with 200-kg weight. It contained mainly milky opal and 3 x 1cm layers of sky-blue and red precious opal (with a beautiful play-of-colour). 13 grinders processed this gemstone for 2 months. There were also a few remarkable findings in 1903 – one 281 carats opal and more 30–50 carats large pieces. In the last years of mining (1919–1921), a piece of a 108 carats precious opal with dimensions of 11×25×38 mm was found. (Butkovič, 1970).

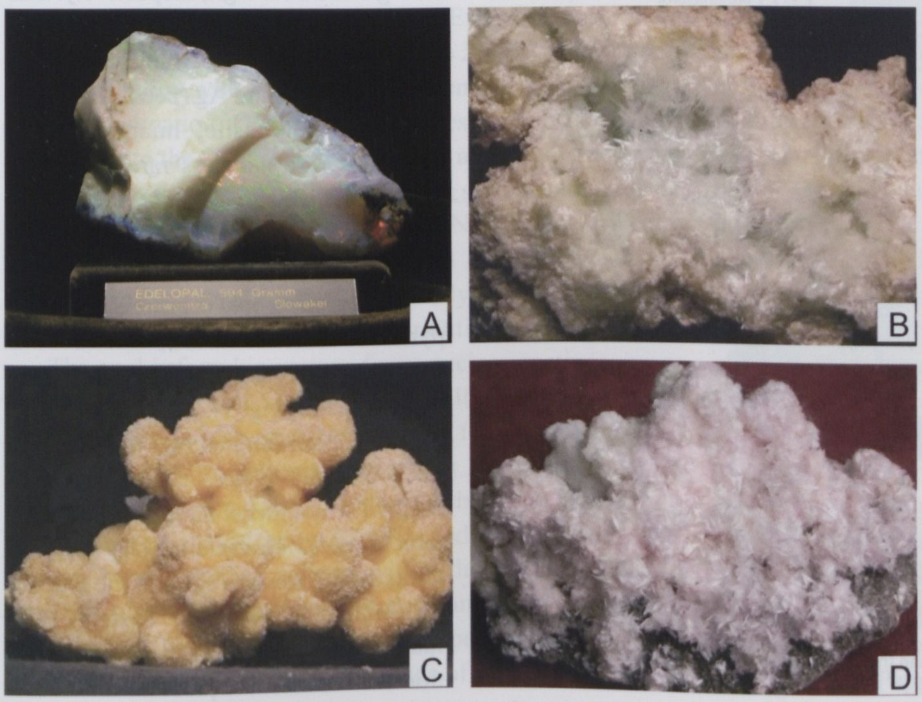


Fig. 13. Minerals from the noble opal mineralization at Červenica (Dubník), Slanské vrchy Mts.

A – The "Vienna Imperial Opal". B – halotrichite, C – alunogene, D – (cobalt-bearing) pickeringite ("kašparite").

3.3.2 Geology and mineralogy of the precious opal mineralization

The most famous deposit of precious opal is located in the middle of the northern part of the Slanské vrchy Mts., on the southern slopes of the Zlatá Baňa stratovolcano (Fig. 5).

The central zone of the Zlatá Baňa stratovolcano is built up by variously altered effusive, extrusive and intrusive bodies of pyroxene andesite and diorite porphyry. Hydrothermal mineralization with zoned alteration patterns and distribution of ore types is centred on diorite porphyry intrusions (Fig. 14). The porphyry intrusions are characterised by K-metasomatic alteration (secondary biotite) and showings of disseminated-stockwork Cu-mineralization at depth. In outcrops, high and low temperature advanced argillic alteration (kaolinite-dickite and kaolinite-halloysite, respectively) with occurrences of natroalunite were developed in relation to barren residual (vuggy) silica bodies especially in the southern part of the mineralized zone (Fig. 14).

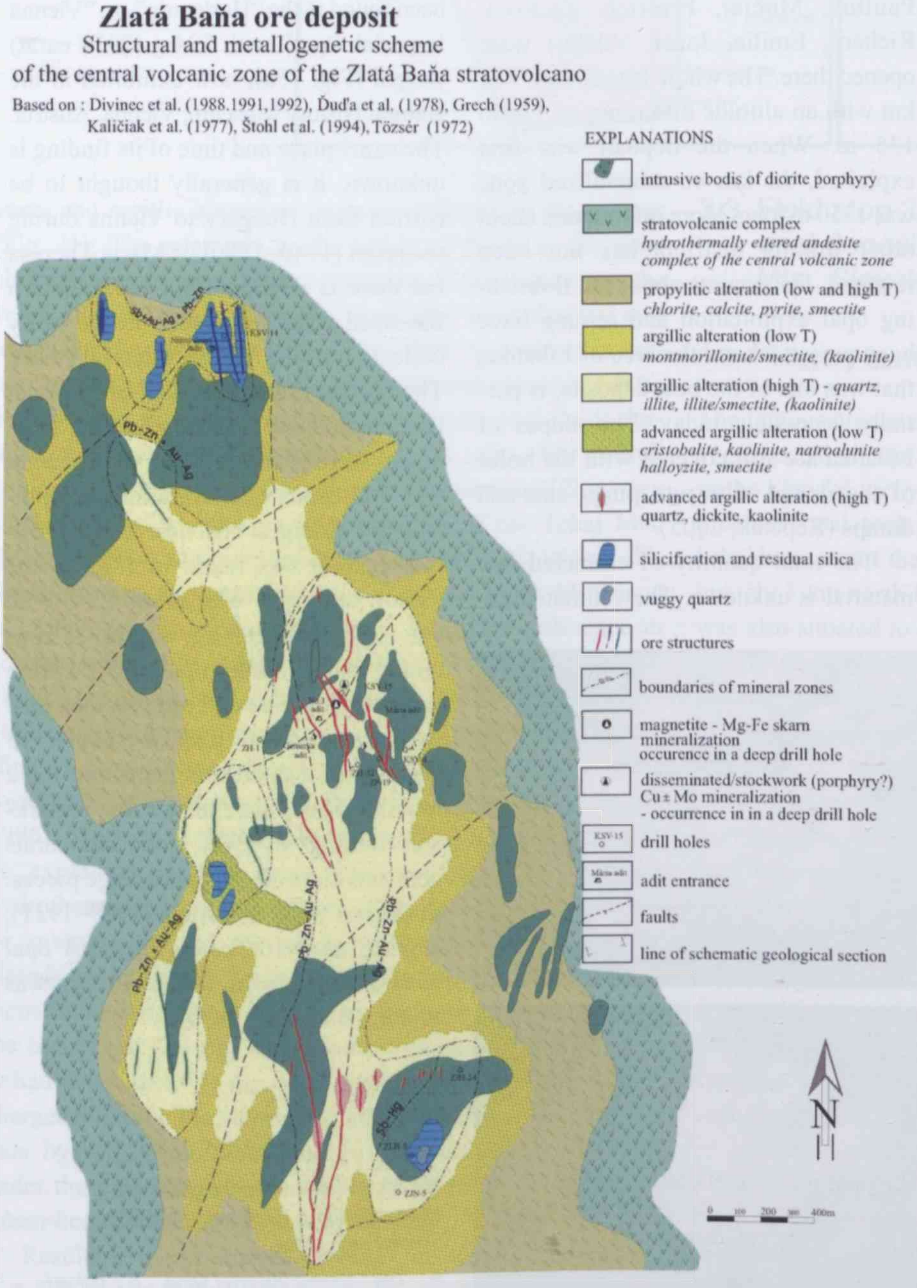


Fig. 14. Hydrothermal alteration and ore mineralization in the central zones of the Zlatá Baňa stratovolcano, Slanské vrchy Mts.

However, the most widespread is the argillic alteration with illite, which has regional distribution in the central part of the volcanic structure. The marginal zones to illite alteration are characterised by smectite alteration and the outermost alteration zone is represented by regional propylitisation with chlorite, calcite, pyrite (Fig. 14).

The illite alteration zones host to base metal sulphide veins, stockworks and hydrothermal breccias with NNW–SSE to N–S strike directions and with 70–90° dips to E as well as W (Figs. 14 and 15). The vein thickness is highly variable, ranging from 0.1 to 5.2 m (average 1,1 m). The central part of the volcanic structure hosts to all mineralization types with dominant presence of Pb-Zn(-Au-Ag) type of ores, however, the marginal parts are characterised by Sb(-Au) and Hg type of ores only. Main ore minerals of the vein mineralization are pyrite, sphalerite and galena accompanied by chalcopyrite, Ag-Pb-Sb sulphosalts, stibnite and cinnabar. The gangue consists of varieties of carbonates and minor amount of quartz. The precious metal mineralization in the deposit is superimposed on the base metal ores and is concentrated in the near-surface parts of veins. The average Au and Ag content in the deposit (in the area of calculated reserves) is 1.42 g/t and 39.74 g/t, respectively. The precious metal mineral association consists of native Au, electrum, native Ag, tellurides of Au and Ag (petzite, hessite), acanthite, polybasite, miargyrite and numerous rare and less rare Ag-Pb-Sb sulphosalts. Reserve of the deposit are 1,623 kt of ore with 1.17% Pb, 2.78% Zn, and 0.1% Cu.

The precious opal deposit is hosted by pyroxene andesite in the 'Libanka lava flows' (12,2–10.0 Ma) of the Zlatá Baňa stratovolcano (Fig. 5). The opal mineralization is concentrated into two, 15-20m thick tectonic zones; each aligned in northwest–southeast directions. The tectonic zone is characterised by pennate faults on the western sides of the Dubník fork of the Svinica fault system. Both faults merge at depth and that intersection zone is also the place of the richest

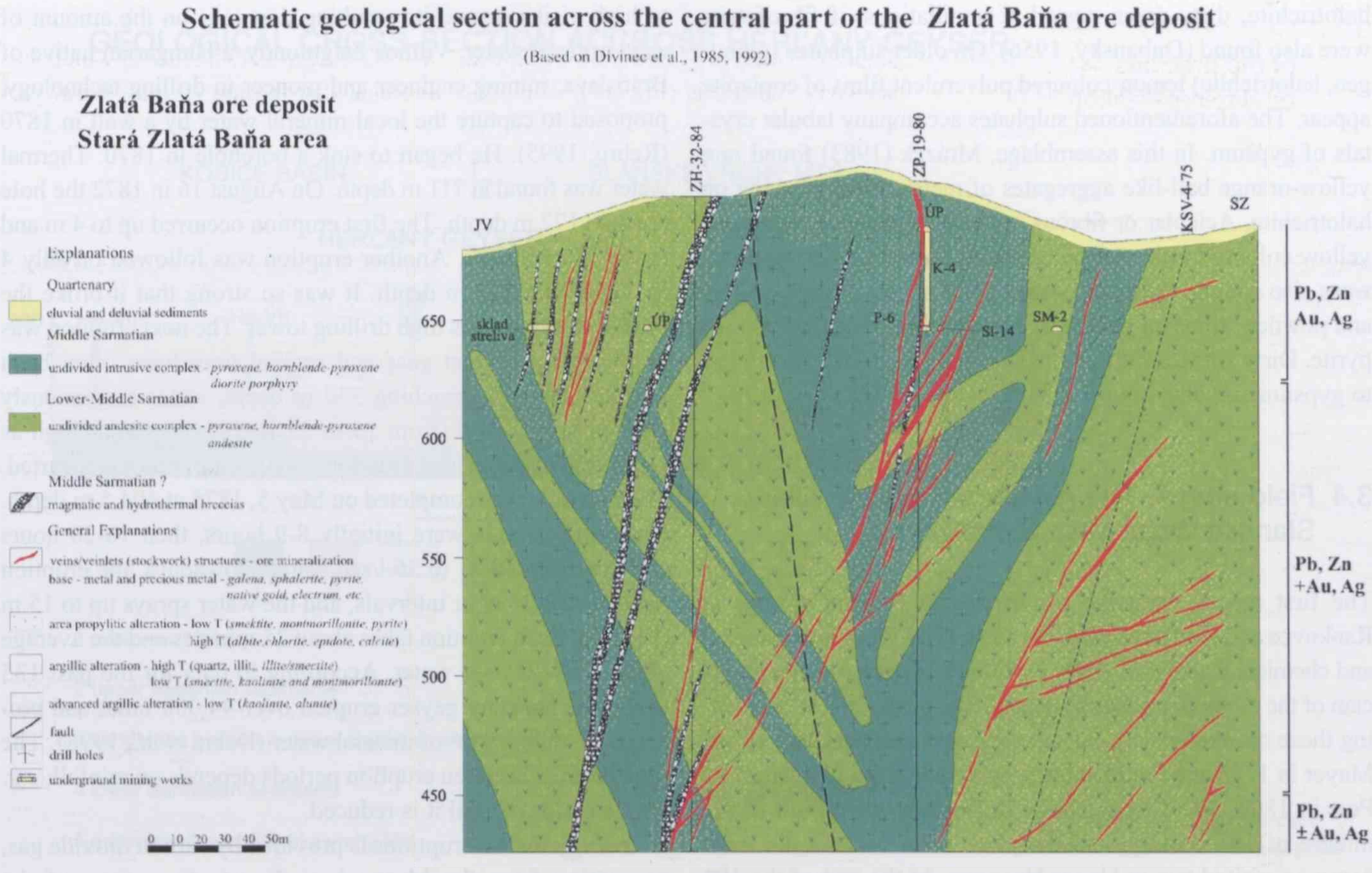


Fig. 15. Section across the central mineralized zone of the Zlatá Baňa stratovolcano, Slanské vrchy Mts.

accumulations of precious opal. Structural analysis and comparison of space orientation of the mineralized and non-mineralzed fissure systems have shown the multiple creation and opening of the fissures even after mineralization. The dominant opal-bearing system consists of extensive fissures with steep to subvertical inclination to the NE and SW and fissures with moderate to steep inclination to the SW. Extensive fissures are characterized by larger thicknesses (up to 25 cm) and by a regular distribution with a NW–SE alignment with steep to subvertical inclination. Opal bearing fissures with mild or steep inclination to the SW are thin veins with a few mm thicknesses only. They form a not well-defined vein system with frequent oscillation of orientations. Fissures with NNE–SSW strike are conspicuous with a steep to subvertical inclination to ESE. The mineralized veins are thin, and mainly located in the great mining narrow rift with a patchy distribution.

The opal is found in various forms such as coatings, irregular vein systems, nests, impregnations, fillings of holes, pores, cracks, fissures and cements of angular rock fragments in breccias.

Infrared spectrophotometric analysis of several samples from the Dubník precious opal showed that most of the SiO_2 material is cristobalite (about 91 wt%) and the opal material is built of by small silica spheres with a diameter of 200–800 nm. 2,4–3 wt% of the spheres have a diameter of about 1000 nm. The high amount of red and other spectral colours in the play-of-colour is due to high percentage of cristobalite spheres with 200–800 nm diameters. Therefore the Dubník opal has a remarkable and extraordinary iridescence, covering the whole colour spectrum (Harman & Chovanec 1980; Costantini, 2005). The opal contains about 3 wt% water and liquid CO_2, acanthite and heulandite inclusions were also found in it.

Also of mineralogical interest are the secondary sulphates created by the decomposition of pyrite and marcasite on the walls of the abandoned adits. The largest and the most remarkable accumulations of those minerals are situated in the less-than-hundred-metres-long so-called “Alunogenka Adit”, and also in the Jozef adit in Libanka Hill. The most abundant sulphates are alunogen and halotrichite. Halotrichite consists of a crust up to 20 cm thick, composed of white-yellow or rusty, slightly acicular and fibrous crystals with a few cm length (Fig. 13b). Chemical analysis (Dubanský, 1956) showed that one a part of the fibrous material consists of iron-bearing pickeringite. There are also few cm thick crystalline aggregates and white or yellow-white crusts of alunogen in association with halotrichite (Fig. 13c). The crusts, grape-like aggregates and coatings of deep green melanterite are also noticeable, however these aggregates quickly loose water and decompose. Another interesting secondary mineral is cobalt-bearing pickeringite, which was originally described by Dubanský (1956) as a new mineral, kašparite (Fig. 13d). This mineral contains about 1,5 wt% of CoO and forms fibrous aggregates of pink or pale violet colour (see Papp, 2004 for further details. In small holes of halotrichite, dirty-green nested accumulations of fibroferrite were also found (Dubanský, 1956). On older sulphates (alunogen, halotrichite) lemon-coloured pulverulent films of copiapite appear. The aforementioned sulphates accompany tabular crystals of gypsum. In this assemblage, Mrázek (1983) found rare yellow-orange ball-like aggregates of metavoltine, growing on halotrichite. Acicular or fibrous crystals of precious white and yellow coloured tschermigite, growing on old timber supports, were also spotted. Sulphur occasionally occurs as soft, yellow and powdery films on intensively propylitized rocks, often with pyrite. Dirty white, brittle crystals of brushite, which are similar to gypsum, are also known from Libanka (Ďuďa *et al.*, 1981).

3.4 Field stop 4. The geyser at Herľany village, Slanské vrchy Mts., Slovakia

The first report about the occurrence of mineral springs at Rankovce and Herľany villages is from 1764. They were studied and chemically analysed firstly by Daniel Textoris, county physician of the Abov (then Abaúj) county. The great interest concerning these mineral waters caused their new analyses by Ludwig Mayer in 1788 and Paul Kitaibel, professor at the University of Pest in 1803. The first facilities in Herľany were built in the middle of 19th century, and the place soon became the most common visited spa in Upper Hungary. At the end of the 19th century, four springs were used for balneological reasons. Owing

Fig. 16. The Herľany geiser at work.

to high visit rate and its resulting demands on the amount of used mineral water, Vilmos Zsigmondy, a Hungarian native of Bratislava, mining engineer and pioneer in drilling technology, proposed to capture the local mineral water by a well in 1870 (Rebro, 1995). He began to sink a borehole in 1870. Thermal water was found at 111 m depth. On August 16 in 1872 the hole reached 172 m depth. The first eruption occurred up to 4 m and lasted five minutes. Another eruption was followed on July 4 in 1873 from 273 m depth. It was so strong that it broke the roof of the 20 meters high drilling tower. The next eruption was in December of that year and several ones have often been repeated then. By reaching 330 m depth, water continuously erupted for 10 days (from 15 to 25/10/1874) up to as high as 112 m. After this major eruption, cyclic eruptions have started. The borehole was completed on May 5, 1875 at 404.5 m depth. Eruption intervals were initially 8-9 hours, then 18-20 hours and they yielded 21 to 36 l/sec water. Nowadays, the eruption recurs in 32-34 hour intervals, and the water sprays up to 15 m (Fig. 16). Each eruption takes about 25 minutes and the average yield is 25-30 l/sec water. According to data for the past 135 years, the Herľany geyser erupted over 44,000 times and produced 22 millions m^3 of mineral water (Dobra *et al.*, 1998). The time interval between eruption periods depends on rainfall; *e.g.* after a major rainfall it is reduced.

Energy for the eruptions is provided by carbon dioxide gas, originating from the Mesozoic carbonate formations of the Veporicum tectonic unit that occur at the base of the Neogene–Pliocene layers of the East Slovak Neogene Basin (Fig. 17). The Neogene basin fill consists of grey silty calcic clay to claystone with foraminifers intercalated by sandstone and rhyolite tuff (pumice tuff and rhyolite breccia epiclastics). Quaternary cover consists of diluvial, proluvial and fluvial sediments of Pleistocene to Holocene.

Prominent feature of basement topography of the East Slovak Neogene Basin is its graben-like nature. In the immediate surroundings of Herľany, subsidence tectonics is characteristic, which is represented by gently dipping N–S oriented faults (Fig. 17). The siliciclastic aquifer of the basin is fed by the hydraulic head of the Slanské vrchy Mts. Water in the aquifer becomes gas-saturated by infiltration of carbon dioxide from the basement rocks along fractures.

The geyser water has 6350 mg/l total dissolved salt content and according to the STN 86 800 standard, it is a medium mineralized sodium chloride-hydrogen carbonate, carbonic-sulfuric water of cold and hypotonic type (Gazda, 1971). During an eruption the temperature changes from 15 °C at the begining to 23 °C at its end. During each eruption the water brings up to the surface particles of fine-grained sand consisting of quartz, plagioclase, ankerite-dolomite, sericite, kaoline, siderite and K-feldspar.

History of the Herľany geyser, including the model of drilling equipment used in the exploratory work by Vilmos Zsigmondy, are documented in the Zsigmondy Museum in Visegrád, Hungary.

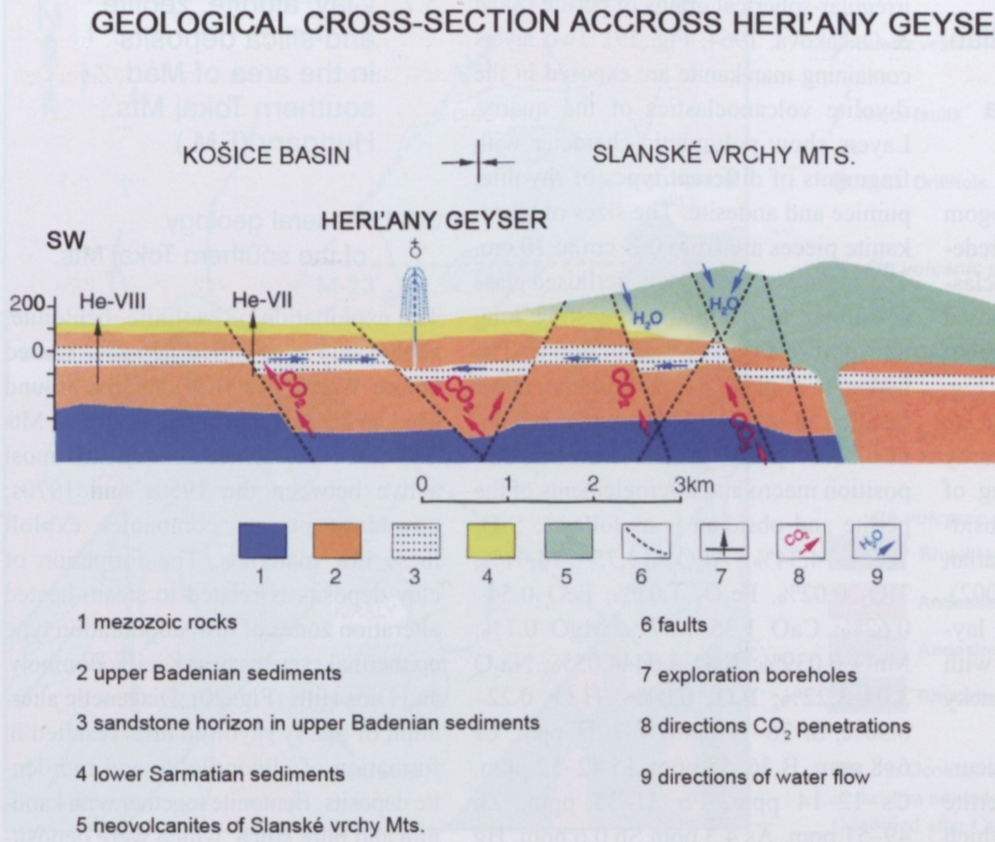


Fig. 17. Simplified geological section across the location of the Herľany geiser.

3.5 Field stop 5. Occurrence of opal near Herľany, Slanské vrchy Mts., Slovakia

A famous occurrence of opal is located approximately 2 km E of Herľany village (Fig. 5), approximately 0.3 km W of the main ridge of Slanské vrchy Mts. along the state road Herľany–Banské. The mineralization is developed in the peripheral zone of the Strechov stratovolcano and the Rankovské skaly volcano of Middle–Upper Sarmatian age. The region of the opal locality is built up by lava flows, redeposited pyroclastics and epiclastics of the above mentioned plaeovolcanoes. The mineralization is hosted by chaotic epiclastic breccia of pyroxene andesite with marks of sorting and graded bedding caused by thin intercalations of epiclastic sandstones as well as redeposited tuffs. Bodies of opal form irregular lenses and bodies in the epiclastics. It is scattered around an area of 200 m². It consists of smaller lenses and veins approximately 10 m long and 1 m thick. (Ďuďa *et al.*, 1985).

Opal of this locality has long been known as "meat opal" with reddish brown, incarnadine, violet and rarely yellow-red to brownish-yellow colour (Fig. 18a). Yellow-white colored varieties with fine black Mn oxide dendrites are rare at this locality (Fig. 18b). Also, along the edges of opal lenses, nests of yellow-green to dirty green "chloropal" occur.

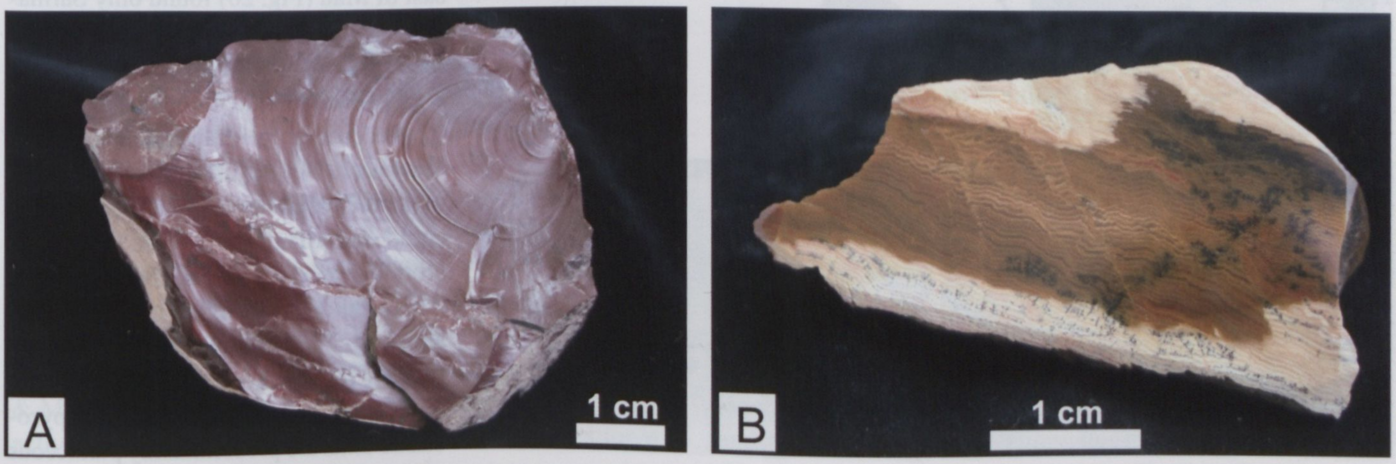


Fig. 18. Opal varieties from Herľany, Slanské vrchy Mts. A – "meat" opal; B – "liver" opal.

3.6 Field stop 6. Volcanic tuffs with obsidian – marekanite at Streda nad Bodrogom, Slovakia (S.J. and P.B.)

In the village of Streda nad Bodrogom (Fig. 2), a cca. 30 m thick bed of redeposited rhyolite and polymictic epiclastic volcanic and tuffitic rocks are exposed in the quarry located on the northern slope of Šibeničný hill (152 m a.s.l.; Fig. 19). Epiclastic rocks contain fragments of perlite and obsidian from the nearby Viničky rhyolite body. K-Ar dating of perlite (12.8 ± 0.5 Ma) as well as obsidian (12.9 ± 0.5 M) prove the Sarmatian age of volcanic rocks (Uhlík *et al.*, 2002). Above the rhyolite volcanoclastic layers, basaltic pyroxene andesite with hyaloclastic breccias also occurs (Baňacký *et al.*, 1989).

The locality is famous for the occurrence of marekanite, a type of perlite named after the Marekanka river which flows into the Okhotsk sea, Siberia. Marekanite consists of obsidian fragments in irregular-spherical grains of perlite (Šalát &Ončáková, 1964; Fig. 19). Two layers containing marekanite are exposed in the rhyolite volcanoclastics of the quarry. Layers show polymictic character with fragments of different types of rhyolite, pumice and andesite. The sizes of marekanite pieces are from 0.X cm to 10 cm. The surface of completely perlitised glass is similar to obsidian suggesting long transport of former obsidian grains. The hydration of glass (*e.g.* perlitisation) never resulted in strong leaching of microelements (except of Hg). The chemical composition macro and microelements of the perlite and obsidian is as follows: SiO_2 72,24–74,34%, Al_2O_3 13,75– 14,01%, TiO_2 0.02%, Fe_2O_3 1.08%, FeO 0.54–0.62%; CaO 1.36–1.37%, MgO 0.1%; MnO 0.039%; K_2O 4.04–4.05%; Na_2O 3.04–3.22%; P_2O_5 0.04%, H_2O^- 0.22–0.30%, Sr 76–77 ppm, V 7–11 ppm, Cr 6–8 ppm, B 56–58 ppm, Li 42–52 ppm, Cs 12–14 ppm, Pb 31–35 ppm, Zn 49–51 ppm, As 4,3 ppm Sb 0,6 ppm, Hg 0,01–0,28 ppm. Part of obsidian fragments can be used as decorative stones.

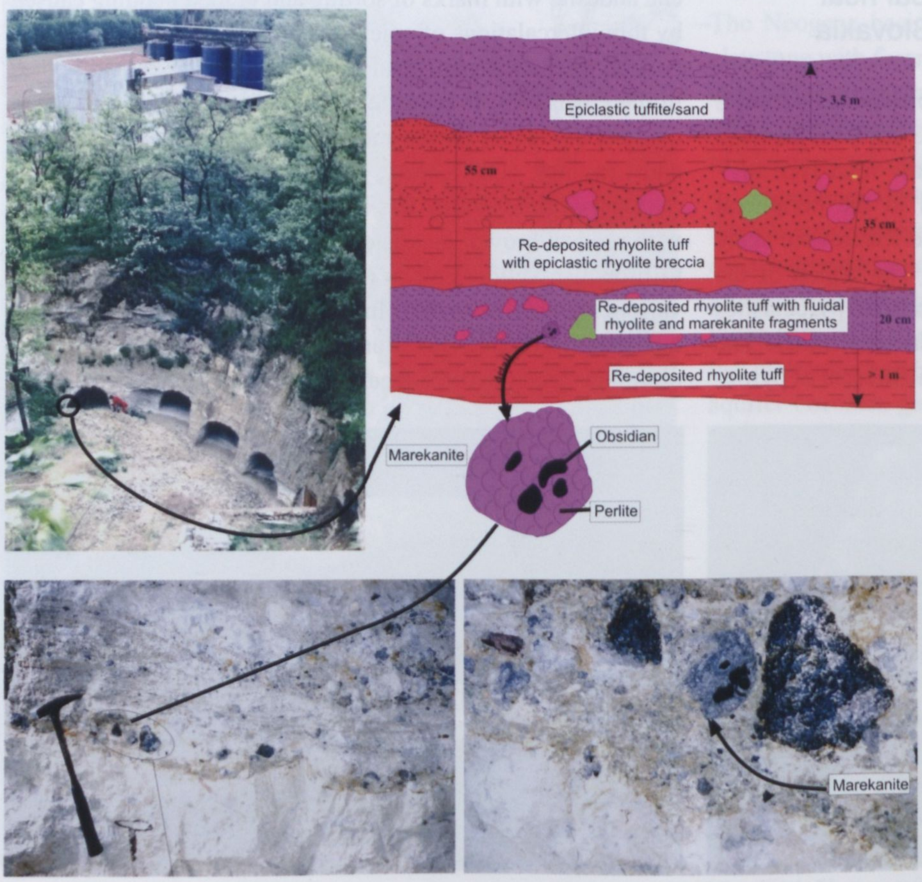


Fig. 19. Occurrence of marekanite at Streda nad Bodrogom, Slovakia.

3.7. Clay, alunite, zeolite and silica deposits in the area of Mád, southern Tokaj Mts., Hungary (F.M.)

3.7.1 General geology of the southern Tokaj Mts.

The exploitation of kaolinite, bentonite, zeolite and pure silica deposits started before World War II in the area around Mád, in the southern part of the Tokaj Mts (Fig. 2). State owned mining was most active between the 1950s and 1970s; nowadays private companies exploit these raw materials. The formation of clay deposits is related to steam-heated alteration zones of low sulphidation type epithermal systems near Király, Bomboly, and Diós Hills (Fig. 20). Diagenetic alteration of glassy rhyolitic tuffs resulted in formation of clinoptilolite and mordenite deposits. Bentonite together with kaolinite and pure silica, which were deposited in local fresh-water basins fed by palaeo-hot springs (distal environments of hydrothermal systems) also form important deposits 1.5 km west of Mád (Fig. 2)

The products of the Badenian volcanic cycle of the Tokaj Mts. are not exposed in the area around Mád. The 1200 m deep Tállya-15 (Ta-15) drillhole (see its location on Fig. 2) reached the Badenian rocks (14.2 Ma K-Ar age; Pécskay & Molnár, 2002) at 900 m depth below the present surface. The Mád-23 drillhole in the center of the mineralized area northeast of Mád (Fig. 20) found only Sarmatian–Pannonian volcanic and sedimentary rocks (11.5-12.2 Ma K-Ar age, Pécskay *et al.*, 1986) to a depth of 712 m.

According to Zelenka (1964) and Mátyás (1974), the major part of the Sarmatian–Pannonian volcanic sequence is composed of five rhyolitic tuff units around Mád (Fig. 21). Each unit reflects the variation of local, subaerial or subaqueous conditions of accumulation and they are locally intercalated with shallow marine clay and marl beds. The pyroclastic units are predominantly pumiceous glass tuff and lapilli bearing pumiceous

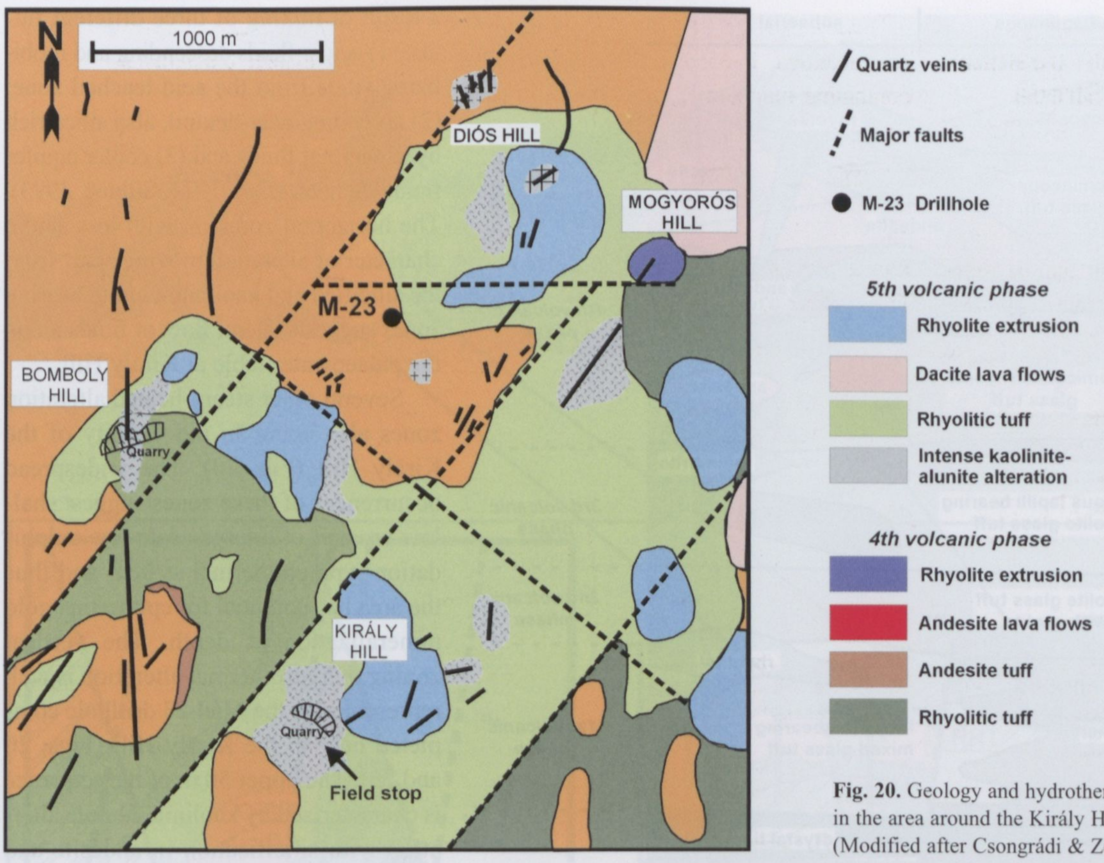


Fig. 20. Geology and hydrothermal alteration zones in the area around the Király Hill at Mád, Tokaj Mts. (Modified after Csongrádi & Zelenka, 1995).

tuff with subordinate crystal tuff as well as ignimbrite. The explosive tuff accumulations are associated with extrusive domes and pumiceous lava flows.

In the mineralized area northeast of Mád, the rhyolitic tuff and associated domes of the fourth explosive phase can be found on the surface (Fig. 20). This phase was followed by andesitic volcanic activity producing lava, tuff and agglomerate beds deposited in shallow water and terrestrial environments. Deposition of the pumiceous rhyolite glass tuff (ignimbrite) of the fifth volcanic phase together with subsequent rhyolite domes and dacitic eruptions (9.8–10.8 Ma K-Ar age; Pécskay *et al.*, 1986) represents the last stages of volcanism in this area. Rhyolite extrusive domes now form the Király Hill, Bomboly Hill and Diós Hill (Fig 20).

The major faults of the area have NE–SW, N–S and E–W directions. The N–S and NE–SW trending faults were active during the hydrothermal processes, indicated by the predominant strike of siliceous veins (Fig. 20). The E–W trending faults were also active after the volcanic-hydrothermal stages, resulting in block tectonism of the volcanic and sedimentary sequences.

The mineralized zones and quartz veins of this area occur in various host rocks including rhyolite and rhyolitic tuff as well as andesitic rocks. K-Ar ages of alunite from the rhyolite of Mogyorós Hill (Fig 20) are 11.7 Ma, whereas alunite from the ignimbrite of Király Hill has an age of 10.9 Ma (Pécskay & Molnár, 2000). These data suggest protracted hydrothermal activity in this area and are in the range of K-Ar ages for volcanic rocks.

3.7.2 Kaolinite and alunite mineralization of the Király Hill at Mád

A horizontal zonation of the steam-heated alteration at shallow depths (along and above the palaeogroundwater-table; see Fig. 4) of a low sulphidation type epithermal system is exposed in the quarry of the Király Hill (Fig. 20). Here the most intensively silicified zones in the fourth and fifth rhyolitic tuff (ignimbrite) units formed along a tectonic contact with the fifth stage rhyolite (Fig 22). The silicification is most intensively developed in the porous rhyolitic tuff; rhyolite is altered only just along the fault. The silicified zone of the fifth tuff unit exposed in the quarry laterally changes into a kaolinite zone with decrease in the SiO_2 content (from about 95–98 wt% to about 80 wt%) and increase of the Al_2O_3 content (from 2–3 wt% to 10–11 wt%). The average sulphate content increases to about 3 wt%, but locally can be as high as 15–20 wt% (chemical data from Mátyás, 1966 and Varjú, 1974). Sulphate-rich zones also have 3–5 wt% K_2O, suggesting that the enrichment of sulfur is associated with the presence of alunite. Nemecz (1973) reported dickite in addition to kaolinite in the kaolinite-alunite zone. The kaolinite-bearing zone is fringed by illite-montmorillonite alteration. According to Nemecz (1973), the illite-montmorillonite has an interlayered structure with ordered pattern of illite and montmorillonite layers (this type of clay mineral was described as 'allevardite' and 'rectorite' in the older literature). The outermost part of this alteration zone contains montmorillonite only.

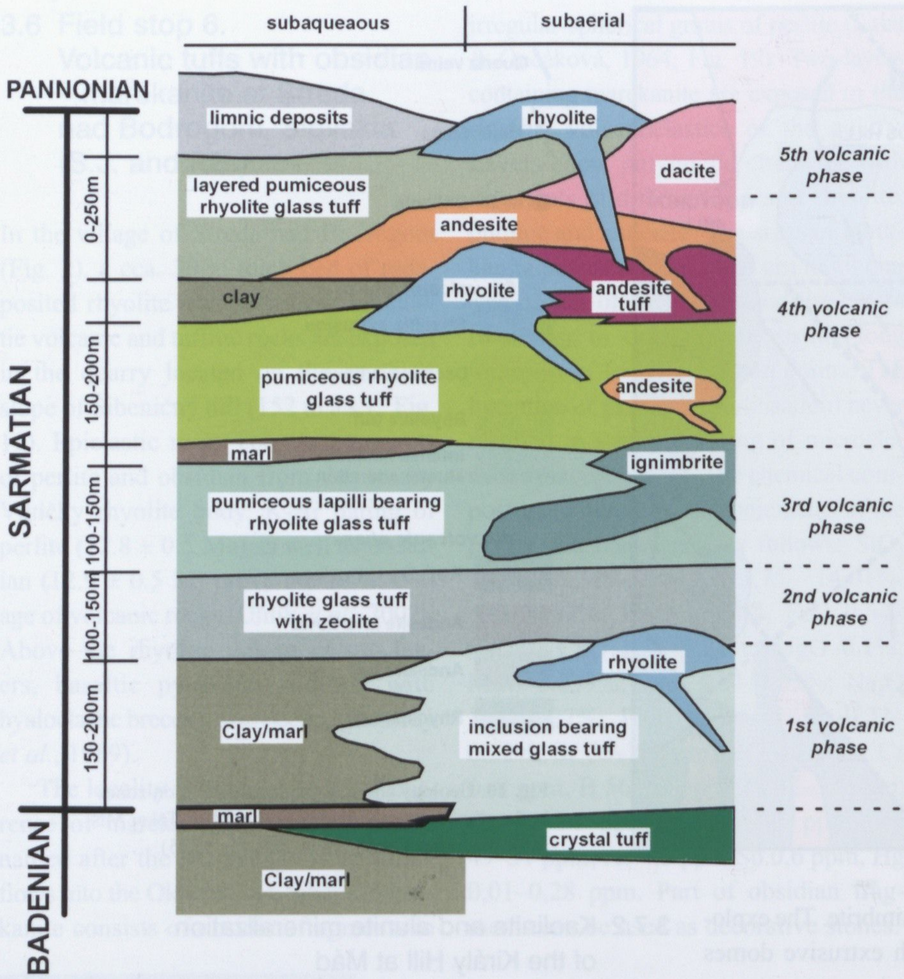


Fig. 21. Volcanic units in the southern part of the Tokaj Mts. (after Zelenka, 1964).

In the strongly silicified zone, the original texture of ignimbrite is totally masked by silicification. As the intensity of silicification decreases towards the kaolinite-alunite zone, the rock becomes highly porous due to hydrothermal leaching. The resulting cavities are mostly found in places of former pumiceous fragments and formed the preferred sites for precipitation of alunite. Alunite is mostly pure K-alunite (minor Na-content may occur in some growth zones; Bajnóczi *et al.*, 2002) and forms aggregates of fine-grained individual crystals (0.1–1 mm) with rhombohedral and platy habit. The 10.8 Ma K/Ar age reported in Pécskay & Molnár (2000) was determined on cavity-filling alunite from this locality. Minor quartz, chalcedony and opal are associated with alunite. Very fine alunite is also present in the kaolinitic-siliceous groundmass of the rock. In the illite-montmorillonite zone, the color of the tuff changes from white to grey/greyish-green. The cavities formed by acidic leaching are less abundant and filled up by illite-montmorillonite or montmorillonite.

No sulphide minerals were found in the alteration zones. The major Fe-bearing mineral is hematite and other Fe oxy-hydroxides. The presence of hematitic patches and disseminations are typical in the marginal parts of the kaolinite-rich alteration zone in other similar shallow epithermal environments of the Tokaj Mts. (Mátyás, 1973).

Steam-heated alteration with alunite forms in a near-surface portion of a low-sulphidation type epithermal environment, where H_2S exsolved through deep boiling of hydrothermal fluids is absorbed into steam-heated water and undergoes oxidation to form H_2SO_4 (Schoen *et al.*, 1974; Henley & Ellis, 1983). At the paleogroundwater table, massive silicification occurs in a porous unit, probably as a result of mixing of three different fluids: (1) acidic fluids descending and mobilizing silica from the acid-leached zone; (2) ascending near-neutral, also silica rich hydrothermal fluids and (3) cooler aquifer fluids (Schoen *et al.*, 1974; Sillitoe, 1993). The horizontal zonation with less acidic character of alteration moving apart from the silicified and kaolinite-alunite bearing zones suggests lateral flow of fluids along the palaeowater table at Király Hill.

Several other steam-heated alteration zones also occur in the vicinity of the Király Hill (Fig. 20). The widespread occurrences of these zones suggest shallow erosion of a large-scale low-sulphidation type epithermal system and thus the area has potential for epithermal gold mineralization at depth. The vertical zoning of hydrothermal alteration is well represented in the Mád-23 drillhole completed near to the Király Hill (Figs. 20 and 23). The upper 50 m of the sequence is characterized by kaolinite-alunite alteration with silicification in andesite and andesite tuff. This is underlain by a zone of K-fledspar-chlorite-carbonate (-smectite-illite) alteration in the subvolcanic andesite. The deeper zones (116–240 m) of this intrusive body are characterized by epidote-carbonate-pyrite-chlorite alteration. Below 240 m depth K-feldspar is present again in the alteration assemblage. The vertical zonation of the hydrothermal alteration within and above the shallow subvolcanic intrusion corresponds to a typical low-sulphidation type epithermal alteration pattern with propylitic zones at depth, adularia-sericite(-chlorite-carbonate) alteration at intermediate depths and steam-heated (kaolinite-alunite) alteration in the shallow portion of the system (Silberman & Berger, 1985).

3.7.3 Zeolitic tuff of the Suba quarry at Mád

The Suba quarry (Geoproduct Ltd., Hungary) at the southwestern foot of the Király Hill near Mád exposes the glassy/pumiceous rhyolite tuff of the second and third eruptive cycles of the southern Tokaj Mts (Fig. 21). The fine-grained matrix of the tuff contains around 1 cm large

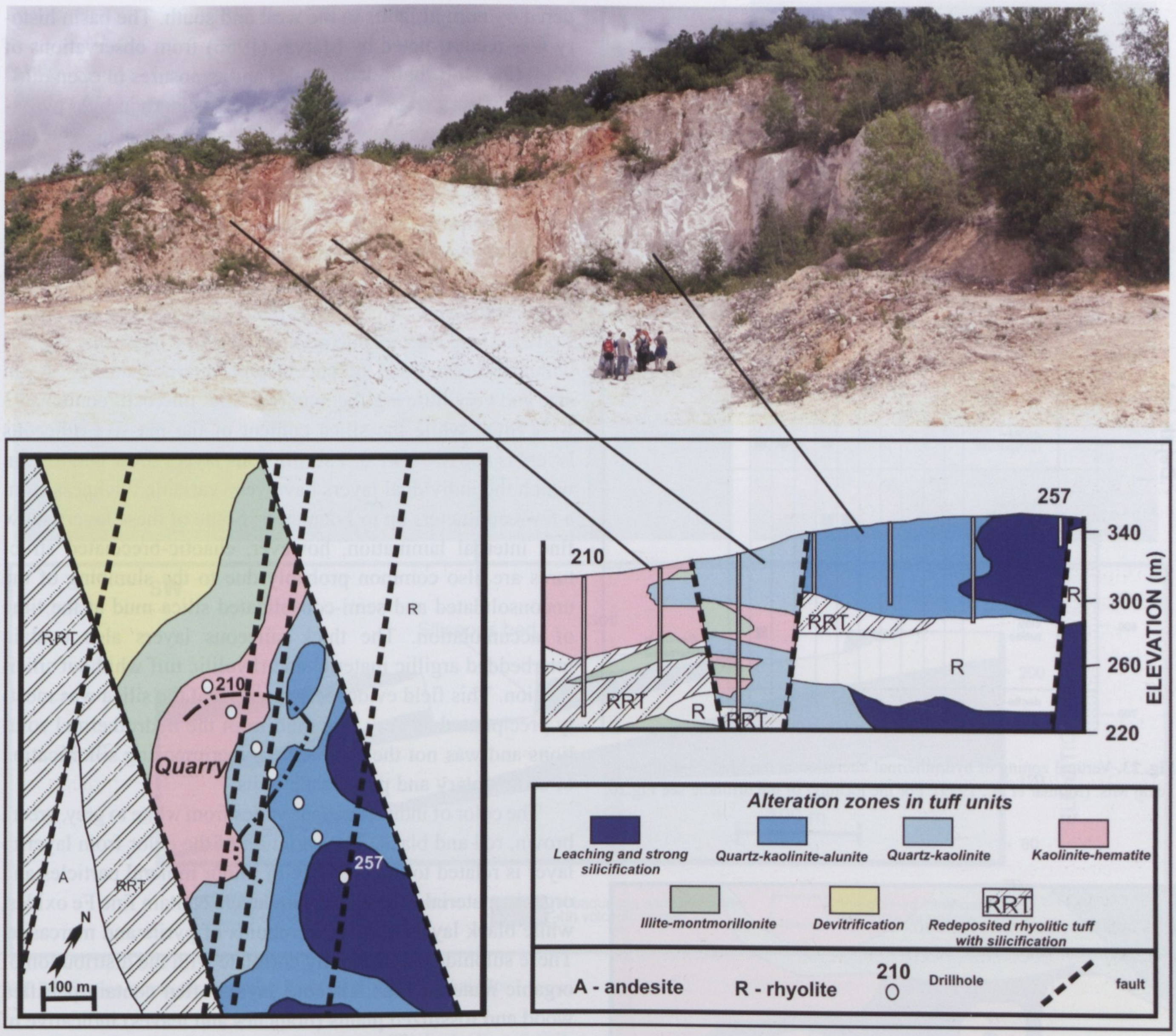


Fig. 22. Zoning of hydrothermal alteration in the steam-heated alteration zone of the Király Hill at Mád, Tokaj Mts. (compiled after Mátyás, 1973 and Nemecz, 1973).

pumice fragments and lithoclasts. Freshly broken surfaces of the tuff have slightly greenish colour and the matrix appears to be silicified at some places, but it generally has rather fresh appearance. However, XRD analyses by Nemecz & Varjú (1963) proved the high zeolite content of the rock. Recent investigations on the zeolitic tuff of this quarry by Kratochvíl *et al.* (2008) found 25% zeolite (18% clinoptiloite and 7% mordenite) content beside opal-CT and smectite and some samples provided the high K-feldspar content, too. Tiny tabular crystals of clinoptilolite with around 10 μm size are associated to smectite either in the groundmass or in the altered pumice fragments. Nemecz & Varjú (1963) have already shown that K-feldspar (adularia) is authigenic (*e.g.* diagenetic) in the tuff and their μm -sized crystals had grown on the surface of pyroclasts. Strongly adularized parts of the tuff contains up to 10 wt% K_2O. The distribution of K-feldspar and zeolites in the rock is determined by the original composition of tuff layers. Adularization preferably developed in the highly potassic glassy tuff layers whereas formation of clinoptilolite together with Na-smectite preferred the more crystalline, plagioclase bearing units. In addition, formation of clinoptilolite released potassium from the volcanic glass and supported formation of adularia in other layers. Thus the alteration of the rhyolitic tuff is related to subaqueous deposition (hydrogenetic argillitization) followed by diagenetic zeolite and adularia formation.

3.7.4 Field stop 9. Silica and clay deposits in a hot-spring fed lacustrine basin west of Mád

The sedimentary sequences of the lacustrine basin west of Mád crop out over an approximately 8 km² area (Figs. 2 and 24). The original size of the basin is not known because it is bor-

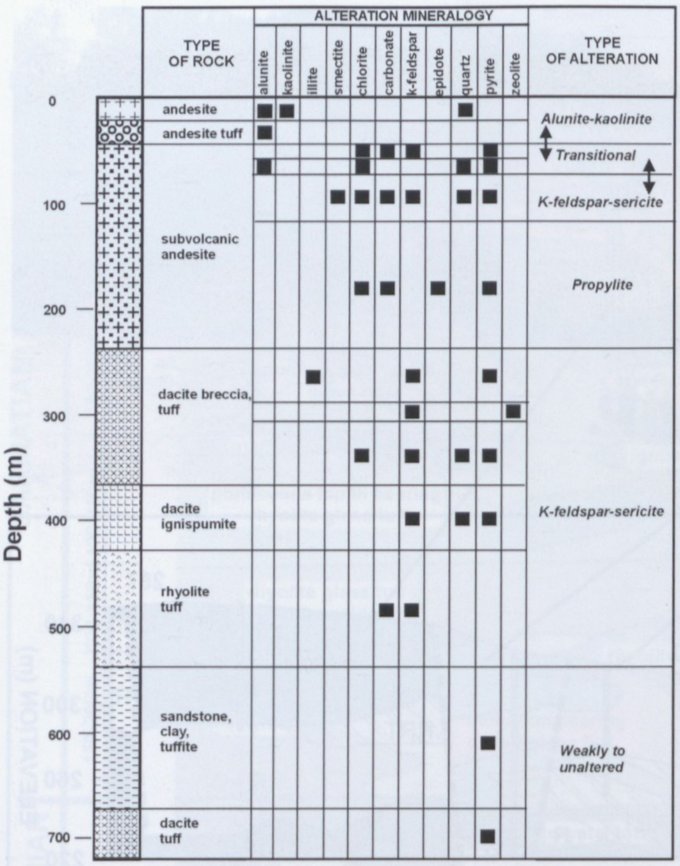


Fig. 23. Vertical zoning of hydrothermal alteration in the Mád-23 drillhole, Tokaj Mts. (Molnár *et al.*, 1999). For the location of the drillhole see Fig.20.

dered by normal faults to the west and south. The basin history was reconstructed by Mátyás (1966) from observations of more than 460 shallow drillholes and exposures in open pits.

The limnic sequence of the basin is underlain by a pyroxene andesite lava flow related to the intermediate volcanic activity between the fourth and fifth rhyolitic tuff unit (Figs. 21 and 25) of the area. The upper parts of the lava beds contain hyaloclastite breccia indicating subaqueous accumulation.

In the lacustrine sedimentary sequence, three major consolidated siliceous layers occur (Fig. 26). The mineral composition of massive silica beds is quartz according to the XRPD studies. There also are unconsolidated beds ('microsil'; Fig. 26) which are composed of uncemented quartz plates 5-20 μm size and very little argillic material. The 'microsil' contains 93 wt% SiO_2, while the silica content of the massive siliceous layers is above 98 wt%. The siliceous layers show bedding, in which the individual layers have very variable thickness from a few centimeters up to 1-2 meters. Some of these layers show fine internal lamination, however, chaotic-brecciated structures are also common probably due to the slumping of the unconsolidated and semi-consolidated silica mud at the time of accumulation. The thick siliceous layers also contain interbedded argillic material and rhyolitic tuff whithout silicification. This field evidence suggests that the silica was mostly precipitated as very fine mud from the hydrothermal solutions and was not the product of superimposing silicification of sedimentary and pyroclastic units.

The color of individual beds varies from white to grey, green, brown, red and black. The variation of the color from layer to layer is related to the presence of minor mineral particles and organic material. Red and brown layers contain fine Fe oxides, while black layers contain framboids of pyrite and marcasite. These sulphides occasionally correlate with the distribution of organic material. The siliceous layers often contain petrified wood and fossilized plants (branches and leaves) indicative of

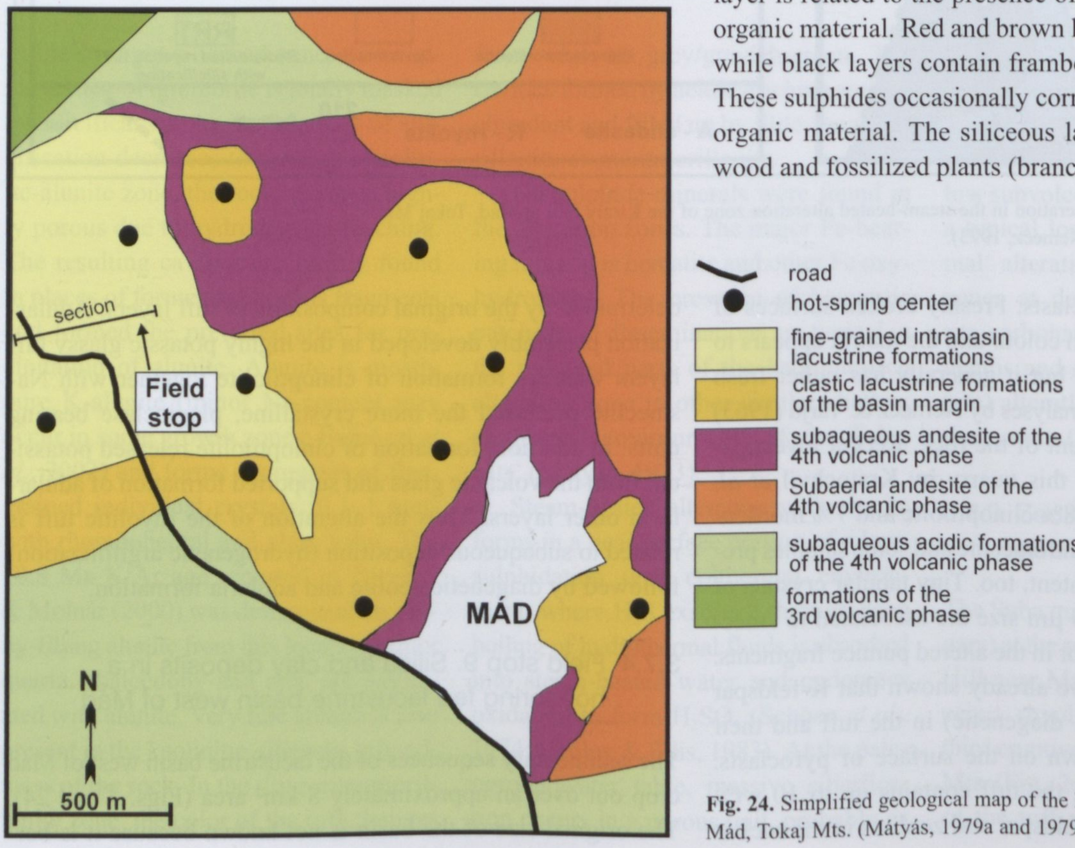


Fig. 24. Simplified geological map of the lacustrine basin west of Mád, Tokaj Mts. (Mátyás, 1979a and 1979b).

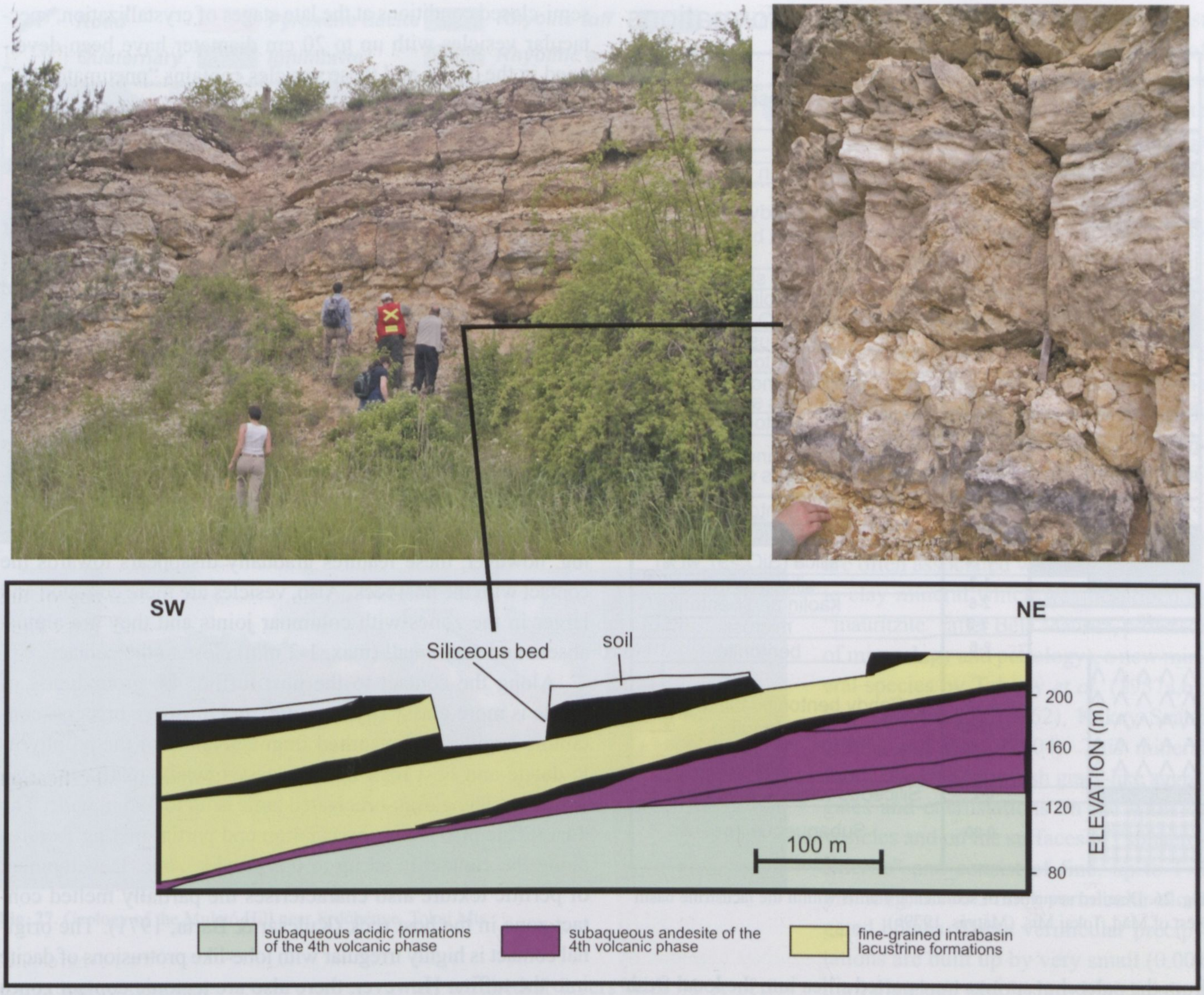


Fig. 25. Section across the lacustrine basin west of Mád, Tokaj Mts.

a shallow water or swamp environment. Typical plant fossils comprise *Glyptostrobus*, *Osmunda*, *Taxodium*, *Populus* and *Salix* species. Prints of *Quercus mediterranea*, *Quercus kubinyii* and *Acer decipiens* transported into the basin from the surrounding areas. The occurrence of relatively low temperature conditions during the accumulation of the silicieous beds is reflected by the presence of tortoise and fish fossils.

The siliceous beds are generally characterized by high concentrations of Sb (up to 400–600 ppm), and lesser As and Hg, as well as some Ag (Vető, 1969; Szakáll, 1990, 1991). Stibnite, stibiconite and realgar sporadically occur in the siliceous beds.

The siliceous layers appear in a cyclic sedimentary series in which the periodicity of sedimentation resulted from the relative intensity of accumulation of terrigenous, pyroclastic and chemically precipitated materials (Fig. 26). The occurrences of tuffite, tuff sand and local conglomerate units indicate the periods of the predominantly pyroclastic and terrigenous source of basin filling. These sediments predominate at the base of sedimentary cycles. Angular pumice fragments are present in each sequence suggesting that basin filling correlates with the fifth eruptive phase in the area. The grain size of sediments gradually decreases, not only horizontally (to the west) but also vertically in each cycle. Thus, the upper parts of sedimentary cycles are characterised by pelitic sediments, which also show intensive kaolinitic and bentonitic alteration near to the hydrothermal vents. The localities of feeder zones within the basin (Fig. 24) are marked by this horizontal zonation of clay minerals (kaolinite close to the feeder zones fringed by a montmorillonite halo) as well as by the thickness of silica layers. Close to the centres, the thickness of siliceous beds is up to 10-12 meters, while on the margins they totally pinch out. In addition to the feeder zones within the basin, Mátyás (1979) also outlined subaerial hydrothermal centres around the depression. These centres now form small hills with strongly silicified and brecciated rocks.

The formation of thick silica mud accumulations in the limnic basin near Mád is interpreted to be distal manifestation of hydrothermal systems of the region. Fluids discharging

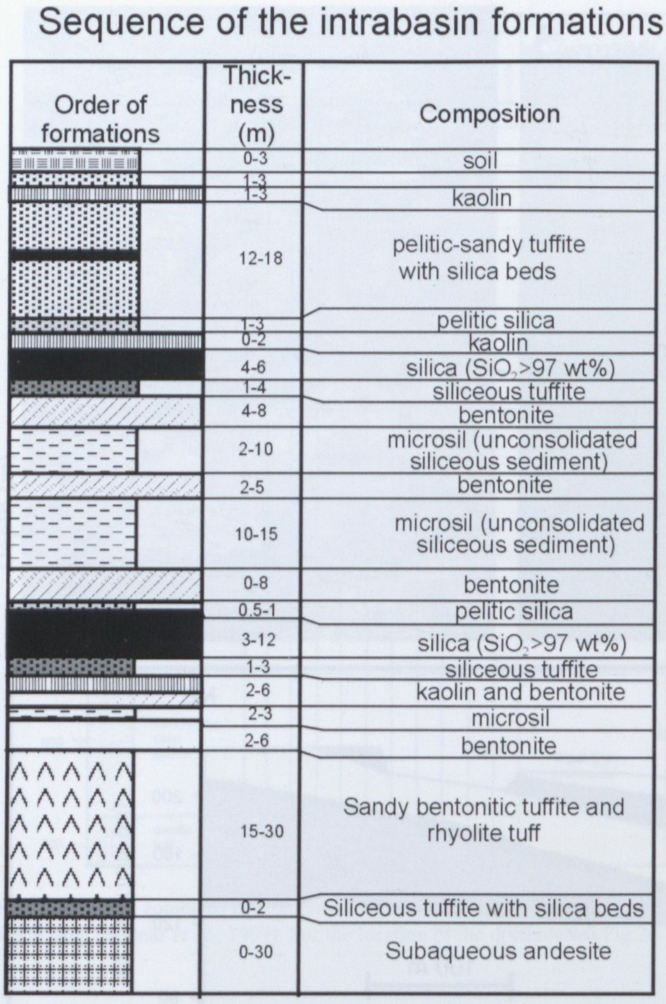


Fig. 26. Detailed sequence of sedimentary units within the lacustrine basin west of Mád, Tokaj Mts. (Mátyás, 1979b).

from the paleo-hot springs transported silica into the local freshwater basin and mixing with cooler and acidic fluids of the organic material rich shallow water/swamp enviroment caused precipitation of siliceous material. In the period of ceased hydrothermal activity mostly terrigeneous sediments and pyroclastic material accumulated in the basin and subaqueous alteration of glassy tuffaceous material led to formation of bentonite and kaolinite beds among the silica layers.

3.8. Field stop 10. The pyroxene dacite laccolith at Erdőbénye, Hungary (F.M.)

3.8.1 Geology and petrology

An Upper Miocene (Sarmatian) pyroxene dacite laccolith is exposed by the Hubertus quarry of the Mulató Hill at Erdőbénye (Figs. 2 and 27). The shape of the igneous body is ellipsoidal in plan view and its known extension is 1.4–0.5 km. The laccolith intruded a fossiliferous Lower Sarmatian rhyolitic tuffite and tuff sequence and crystallized at shallow, possibly a few hundred metres depth only. Due to the volatile enrichment and semi-closed conditions at the late stages of crystallization, spectacular vesicles with up to 20 cm diameter have been developed in the dacite and these vesicles contains "pneumatolytic" and hydrothermal mineralization rich in SiO_2 and carbonate minerals among other silicates.

The main mass of the laccolith consists of micro-porphyritic dacite with plagioclase phenocrysts (An_{35-56}, 1–3 mm) included in the pilotaxitic-microholocrystalline groundmass (Kulcsár & Barta, 1971; Gyarmati, 1974; Rózsa, 1993). The amount of ferroaugite-pigeonite phenocrysts is subordinate (2–3%) and olivine, ilmenite and apatite are rare accessories. The groundmass/phenocryst ratio is around 75:25. Representative whole-rock chemical composition is shown in Table 4.

The Hubertus quarry exposes E–W and N–S oriented sections with approximately 800 m total length across the central-upper zones of the laccolith and contacts to the host tuffite (Fig. 27). The central zones of the igneous body are characterized by spectacular columnar joints as the result of relatively slow cooling, however, these features gradually disappears towards the contact with the host rock. Also, vesicles are more common and larger in the zones with columnar joints and they are almost absent and very small (max. 1-2 mm) close to the contact.

Along the contact to the host tuffite, the groundmass of dacite is more glassy (hyalopilitic) and intrusive breccias containing angular and resorbed fragments both of the porphyritic dacite and host rock in the glassy igneous matrix are also common. The glassy-brecciated zone is up to 3–5 m wide. The host tuffite also shows brecciation and partial meting features along the contact in an up to 0.5 m wide zone. Development of perlitic texture also characterises the partially melted contact zone in the host rock (Kulcsár & Barta, 1971). The original contact is highly irregular with lobe-like protrusions of dacite into the tuffite. However, there also are tectonic contact zones due to the superimposing faulting.

Table 4. Whole-rock chemical composition of the pyroxene dacite, Mulató Hill, Erdőbénye, Tokaj Mts. (Gyarmati, 1977).

	wt%
SiO_2	63.62
Al_2O_3	16.06
Fe_2O_3	1.85
FeO	3.41
MnO	0.12
MgO	0.14
CaO	3.05
Na_2O	4.04
K_2O	3.11
TiO_2	0.62
P_2O_5	0.04
CO_2	1.28
$^{+}H_2O$	1.05
$^{-}H_2O$	2.06
Total	100.45

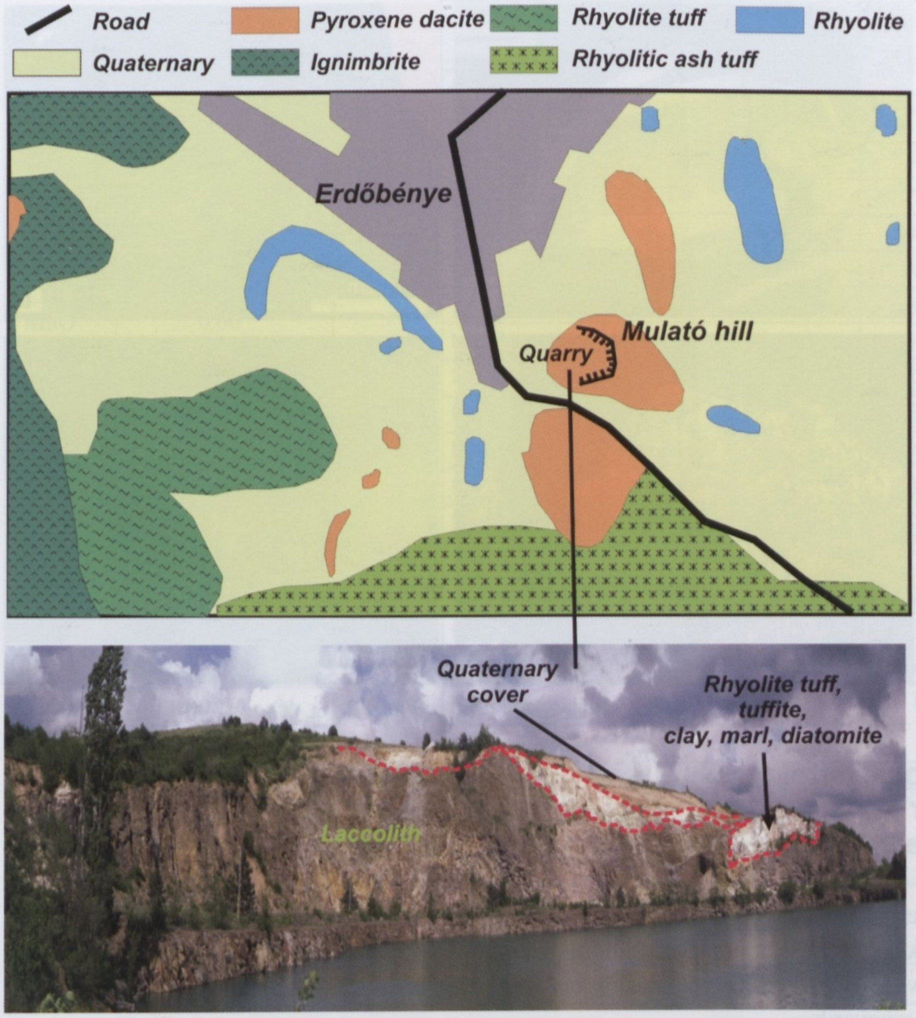


Fig. 27. Geology of the Mulató Hill near Erdőbénye, Tokaj Mts.

3.8.2 Mineralization

The vesicles of the dacite laccolith obviously were formed at the late stage of crystallization when the pressure of segregated volatile phases was able to blow up gas cavities in the still ductile igneous body. The first stage of mineralization was formed under these "pneumatolytic" conditions and are represented by small (max. 3–4 mm) euhedral crystals along the walls of cavities (Molnár & Takács, 1993; Szakáll, 1993). The most common mineral in the "pneumatolytic" assemblage is tridymite: some of the cavities contains rather spectacular triple twins of hexagonal tablets (Fig. 28a). HRTEM studies showed that the ordering of tetrahedral layers in the structure of tridymite resulted in formation of superlattices with different periodicities. Most common is the polytype consisting of ten tetrahedral layers with 41 Å periodicity. In a few cavities, occurrences of small (< 1mm) cristobalite octahedra, as well as quartz with short primatic hexagonal habit were also detected in association with tridymite. Among the silicates, the most common "pneumatolytic" minerals are the sanidine and plagioclase. Less common is the occurrence of prismatic hornblende crystals. Rare accessories are octahedra of magnetite, which show oriented intergrowth with ilmenite at some places and needle-like prisms of apatite.

Mineralization of hydrothermal origin also occurs in the vesicles of dacite and it forms the most spectacular paragenesis of the locality. The most common hydrothermal minerals are the carbonates with globular-sphaeroidal habit (Figs. 28c and 28d). These brownish *"sphaerosiderite"* precipitations reach several centimetre diameters on the walls of cavities. Most commonly they consist of minute rhombohedral crystals of siderite but their compositions are often transitional to rhodochrosite and calcite depending on the amount of Mn and Ca in the structure. The Fe/Mn/Ca ratios are variable according to the banded internal structure of "sphaerosiderite", however, the outher zones and fibrous-elongated masses of carbonate grown on the surface of sphaeroids often have calcite or rhodochrosite compositions (Weiszburg *et al.*, 1993a). It is interesting that the Mg content of carbonates are insignificant, however, it is understandable considering the strongly depleted MgO content of the host rock (Table 4).

The "sphaerosiderite" precipitations are often associated with a rather specific clay mineral which was described as "mauritzite" (after Béla Mauritz, professor of mineralogy and petrology), a new mineral species by Tokody *et al.* (1957a,b). See also Tokody (1962), Kákay Szabó (1983) and Papp (2004). This mineral forms blackish-brownish grass-like aggregates and encrustations on the walls of vesicles and on the surfaces of "sphaerosiderite" and consist of fine, up to 1–5 mm long, 0.1–0.2 thick vermicular-elongated bodies. These vermicular precipitations are built up by very small (0.001 mm) platelets, which show bluish colour under microscope. X-ray and electron-diffraction studies proved that the peculiar mineral has smectite structure and considering the chemical composition it can be classified as a Fe-rich saponite (Weiszburg *et al.*, 1993b). Repeated Mössbauer-spectroscopic analyses carried out periodically on the same sample during the past 15 years proved that the Fe(II)-content of the mineral is continuously oxidizing under atmospheric conditions thus the composition is gradually changing into ferrisaponite (T. Weiszburg, personal discussion, 2010).

Silica minerals also occur in large variety in the hydrothermal paragenesis (Molnár & Takács, 1993). Among them opal-C and opal-CT encrustations, leaf-like plates and aggregates (Fig. 28b) of tubular forms are common as coloured wax, liver and milk opal, as well as bluish

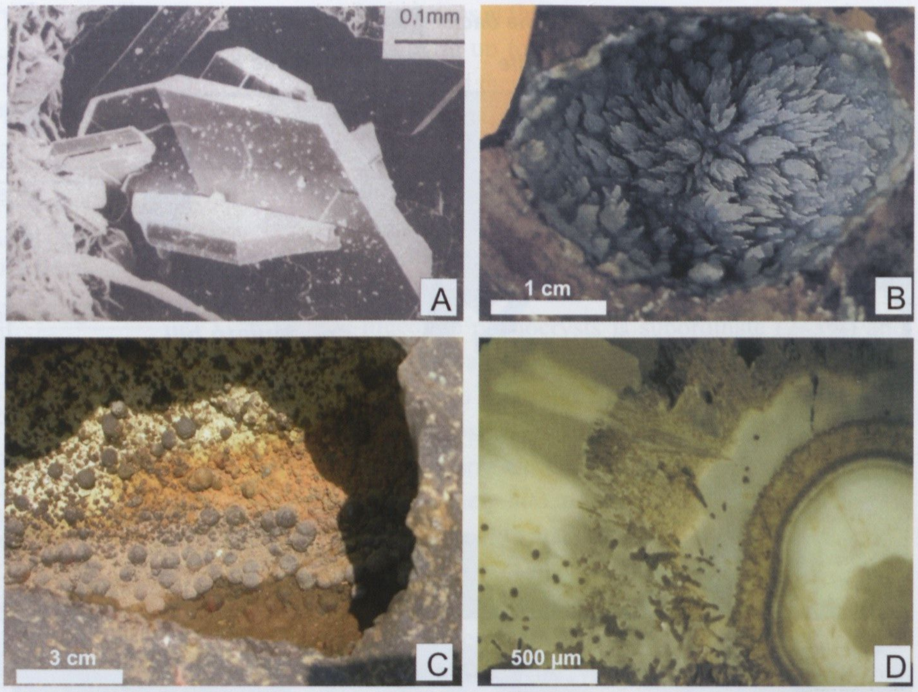


Fig. 28. Minerals from the vesicles of the laccolith at Erdőbénye, Tokaj Mts.
A – tridymite, twinned tabular crystal (SEM photograph); B – opal; C – sphaerosiderite globules; D – cross section of a sphaerosiderite globule.

hialite along the walls of cavities or on the surface of carbonate sphaeroids. Precipitation of opal varieties was followed by encrustation of chalcedony and quartzine (chalcedony with positive optical elongation) at many places. The final silica precipitation is short prismatic quartz with up to 5 mm long crystals.

Less common minerals in the hydrothermal paragenesis are native sulphur, marcasite, cassiterite, hematite, barite, gypsum and sylvite (Szakáll & Kovács, 1993). Secondary minerals are goethite and Mn oxides.

3.9. Field stop 11. Example of a Tokaj terroir and its wine: the Lőcse terroir at Erdőbénye, Tokaj Mts., Hungary (A.N.)

Although a terroir cadastre of the Tokaj terroirs exists since 1730, the scientific qualification of the Tokaj terroirs has not been made yet. There is an example below, to illustrate how such a work should be done for most of the vineyards.

The Lőcse terroir in Erdőbénye village (Figs. 2 and 29) is quite famous since the 18th century because of its high quality wines. The terroir and its wine represent well the advantages of a high-ranked Tokaj vineyard. The terroir is cultivated nowadays by the Béres Winery and they produce superior quality dry furmint wines from this area.

Details of the Lőcse terroir are as follows:

- *Area*: 10 ha
- *Year of plantation*: 1982
- *Grape variety*: 50% Furmint, 50% Hárslevelű
- *Height above sea level*: 180–215 m
- *Orientation*: SW–W
- *Dip of slope*: 15°
- *Basement rock*: Early Sarmatian rhyolitic tuff and ignimbrite, rich in pumice. The 100 m thick pyroclastic sequence is interbedded by bentonite layers and veins of chalcedony. The average composition of the bedrock is summarized in Table 5.
- *Soil*: at the foot of the slope the soil is thicker (~1 m), loam, clayey loam with perlite grains and rhyolite tuff debris, at the top of slope thinner (0.2–0.3 m) rhyolite tuff debris and "rock flour" in loamy matrix. Chemical characteristics of the soil are summarised in Table 6.

Wine:

- High sugar content in the harvested juice and high percentage of the fermented alcohol (favourable orientation and dip of slope, great amount of heat)
- Full bodied (sub- and top-soil rich in elements)
- Medium (vintage 2007) and high (vintages 2006 and 2008) acidity because of high values of Ca and Mg

Results of analysis of wine are listed in Table 7.

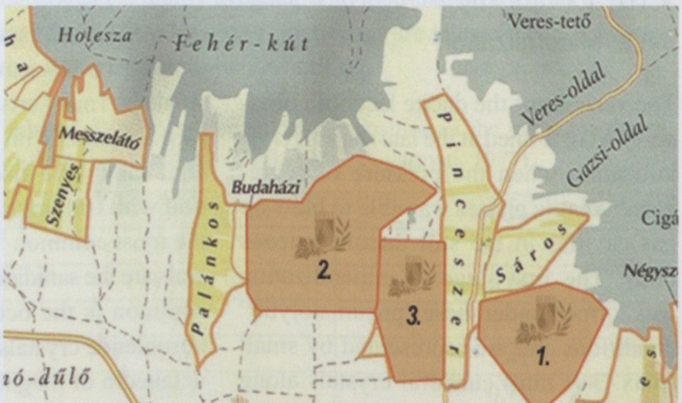


Fig. 29. Terroirs of the Béres Winery at Erdőbénye, Tokaj Mts.
1 – Lőcse and Herczeg terroirs; 2 – Felhegy-Zsákoshegy terroir; Diókút Valley terroir.

Table 5. Average composition of the bedrock in the Lőcse terroir, Béres Winery, Tokaj Mts.

	wt%
SiO_2	56.26
Al_2O_3	19.39
Fe_2O_3	4.96
FeO	0.25
MnO	0.06
MgO	0.48
CaO	1.75
Na_2O	0.80
K_2O	1.12
TiO_2	1.01
P_2O_5	0.06
CO_2	0.00
$+H_2O$	9.62
$-H_2O$	4.43
Total	100.19

Table 6. Chemical characteristics of the soil in the Lőcse terroir, Béres Winery, Tokaj Mts.

Molnar *et al.* Table 6

	Unit of measurement			
Depth of sampling	cm	0–30	30–60	60–120
pH (KCl)		5.22	4.89	
Consistency	K_A	37	37	39
Total salt	%	<0.02	<0.02	<0.02
$CaCO_3$	%	0	0	0
TOC	%	1.39	0.97	0
NO_3–NO_2–N	mg/kg	<1	<1	
NH_4–N	mg/kg	2.0	2.0	
P_2O_5	mg/kg	82	11	
K_2O	mg/kg	2.98	138	
Mg	mg/kg	312	400	
Na	mg/kg	21	37	
Zn	mg/kg	2.7	1.5	
Cu	mg/kg	100	22	
Mn	mg/kg	415	425	
pH (H_2O)		6.57	6.64	6.40
hydrolitic acidity	Y_1	10.0	8.76	

Table 7. Some chemical characteristics of the Lőcse furmint from the past years.

Characteristics	'06 Lőcse Furmint	'07 Lőcse Furmint	'08 Lőcse Furmint
Brix° at harvest, %v/v	20.5	21	21
effective alcohol, %v/v	13.5	14.34	13.58
sugar-free extract, g/l	24.7	21.1	26.6
citric acid, g/l	8.7	5.9	6.4
pH	3.15	3.29	3.47

3.10. Concluding remarks on the Tokaj wines after the field experience

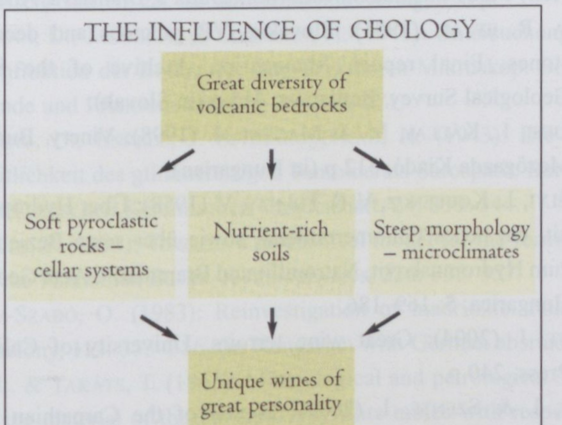


Fig. 30. Geological factors influencing the quality of Tokaj wines.

The high quality and unique character of the Tokaj wines can be attributed both to natural conditions and the human handycraft. Among the natural conditions the meso- and microclimate play a leading role, among the biological conditions the local microflora (fungi) are important.

Among the geological factors the most important ones are (Fig. 30):

- Great diversity of volcanic bedrocks
- Nutrient-rich soils
- Steep morphology (microclimates)
- Soft pyroclastic rocks and cellar systems

How is a typical classical Tokaj wine? Their bouquet is usually showing *Botrytis*-notes. Not speaking about the dry *ordinarium*, most Tokaj wines contain more or less residual sugar, from 3 g/l up to 250–260 g/l. The wines are usually full bodied, highly acidic, thus balancing the dominant effect of sugar. Their aromas reflect the micro-oxidation having gained during a long maturation in the cask. The volcanic sub-soil leaves a "fingerprint" upon most of these wines lending them a "mineralic taste".

4. Acknowledgements

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5. References

Ahn, J.H. & Buseck, P.R. (1990): Layer-stacking sequences and structural disorder in mixed-layer illite/smectite: Image simulation and HRTEM imaging. American Mineralogist, **75**: 267–275.

Alkonyi, L. (2000): Tokaj: The wine of freedom – A szabadság bora. Budapest: Spread Bt, 239 p (bilingual).

Andreánszky, G. (1959): Die Flora der sarmatischen Stufe in Ungarn. Budapest: Akadémiai Kiadó, 360 p.

Bacsó, Z. (2000): Geology and mineralogy of the submarine volcanogenic sulphide deposit, near Brehov in Eastern Slovakia: a genetic ore formation model. Mineralia Slovaca, **32**, 265–267.

Bacsó, Z. & Ďuďa, R. (1988): Metallogenesis and ore formations of the Remetské Hámrte ore field. Mineralia Slovaca, **20**: 193–220.

Bajnóczi, B., Molnár, F., Maeda, K., Nagy, G. & Vennemann, T. (2002): Mineralogy and genesis of primary alunites from epithermal systems of Hungary. Acta Geologica Hungarica, **45**: 101–118.

Balla, Z. (1987): Tertiary paleomagnetic data for the Carpatho-Pannonian region in the light of Miocene rotation kinematics. Tectonophysics, **139**: 67–98.

Ballenegger, R. (1917): About the "nyirok" soil of Tokajhegyalja. Földtani Közlöny, **47**: 20–24 (in Hungarian).

Baňacký, V., Vass, D., Kaličiak, M., Remšík, A. & Pospíšil, Ľ. (1987): Explanations to the geological map of the northern part of the Východoslovenská nížina. Bratislava: GÚDŠ, 117 p (in Slovak).

Baňacký, V., Elečko, M., Kaličiak, M., Straka, P., Škvarka, L., Šucha, P., Vass, D., Vozárová, A. & Vozár, J. (1989): Explanations to the geological map of the southern part of the Východoslovenská nížina and Zemplínske vrchy Mts. Bratislava: GÚDŠ, 143 p (in Slovak).

Bergaya, F., Beneke, K. & Lagaly, G. (2001): History and perspectives of clay science. ECGA Newsletter, **4**: 5–41.

Berger, B.R. & Henley, R.W. (1989): Advances in the understanding of epithermal gold-silver deposits, with special reference to the western Unites States. Economic Geology Monograph, **6**: 405–423.

Beutelspacher, H. & van der Marel, H.W. (1968): Atlas of electron microscopy of clay minerals and their admixtures. Amsterdam: Elsevier, 333 p.

Boczán, B., Franyó, F., Frits, J., Láng, S., Moldvay, L., Pantó, G., Rónai, T. & Stefanovits, P. (1966): Sátoraljaújhely. Explanation to the geological map series of Hungary in 200,000 scale. Budapest: Magyar Állami Földtani Intézet (in Hungarian).

Bonham, H.F., Jr. (1988): Models for volcanic-hosted epithermal precious metal deposits. In Schafer, R.W., Cooper, J.J. & Vikre, P.G. (eds): Bulk mineable precious metal deposits of the Western United States. The Geological Society of Nevada Symposium Proceedings, April 6–8, 1987, 259–271.

Botos, E. & Marcinkó, F. (2005): Atlas of Tokaj wines. Budapest: Bor-Kép (in Hungarian).

Burian, J., Slavkay, M., Štohl, J. & Tözsér, J. (1985): Metallogenesis of neovolcanites in Slovakia. Mineralia Slovaca Monografia, Bratislava: Alfa, 269 p.

Butkovič, Š. (1970): History of the Slovak precious opal from Dubník. Bratislava: Alfa, p. 267 (in Slovak with German, English and Russian summary).

Clarke, O. & Rand, M. (2001): Clarke's grosses Lexikon der Rebsorten. München: Droemersche Verlagsanstalt, 320 p.

Costantini, L. (2005): The Slovak opal – A rediscovery of the queen of gems. Kežmarok: ViViT, 282 p.

Csongrádi, J. & Zelenka, T. (1995): Hot-spring type gold-silver mineralization in the Tokaj Mts., northeastern Hungary. Geological Survey of Greece, Special Publication, **4**: 659–693.

Csontos, L., Tari, G., Bergerat, F. & Fodor, L. (1991): Evolution of the stress fields in the Carpatho-Pannonian area during the Neogene. Tectonophysics, **199**: 73–91.

Csontos, L., Nagymarosy, A., Horváth, F. & Kovác, M. (1992): Tertiary evolution of the Intra-Carpathian area: a model. Tectonophysics, **208**: 221–241.

Dobra, E., Bogdanovská, M., Ciberej, J., Ďuďa, R., Fulín, M., Kaličiak, M., Sitášová, E., Varga, G. & Šťastný, P. (1998): Herľany and surroundings. Košice: Dom techniky C PRESS s.r.o., 41 p (in Slovak).

Dódony, I. (1985): Transmission electron microscopic investigations of crystal chemical relations and lattice geometry of layer silicates. CSc Thesis, Manuscript, Budapest, Library of the HAS. 3+115 p. (in Hungarian).

Downes, H., Pantó, Gy., Póka, T., Mattey, P.B. & Greenwood, P.B. (1995): Calc-alkaline volcanics of the Inner Carpathian arc, Northern Hungary. New geochemical and oxygen isotope results. Acta Volcanologica, **7**: 29–41.

Dubanský, A. (1956): Contributions to the knowledge of secondary sulfates III. Sulfates from Dubník near Prešov. Chemické Listy (Praha), **80**: 1347–1361.

Ďuďa, R, Černý, P., Kaličiak, M., Tözsér, J., Ulrych, J. & Veselovský, F. (1981): Mineralogy of the north part of the Slanské vrchy Mts. Mineralia Slovaca Monografia 2, Bratislava: Alfa, 98 p.

Ďuďa, R. et al. (1985): Slovakia. VP, precious and decorative stones. Final report. Manuscript. Archive of the Slovak Geological Survey, Bratislava, 415 p (in Slovak).

Eperjesi, I., Kállay, M. & Magyar, I. (1998): Vinery. Budapest: Mezőgazda Kiadó, 312 p (in Hungarian).

Erdélyi, J., Koblencz, V. & Tolnay, V. (1958): Über Hydroparagonit, ein neues Glimmermineral, sowie über seine Beziehungen zum Hydromuskovit, Natronillit und Brammallit. Acta Geologica Hungarica, **5**: 169–186.

Fanet, J. (2004): Great wine terroirs. University of California Press, 240 p.

Főzy, I. & Szente, I. (2007): Fossils of the Carpathian Basin. Budapest: Gondolat Kiadó (in Hungarian).

Gazda, S. (1971): Modification of the Palmer classification system. Hydrogeological yearbook 1970–1971. Bratislava: Geologicky ústav Dionýza Štúra, 122–126 (in Slovak).

Grim, R.E. (1953): Clay mineralogy. New York: McGraw-Hill, 384 p.

Grim, R.E. & Bradley, W.F. (1948): The illite clay minerals. In International Geological Congress, 18th Session, Great Britain, 1948. Volume of Titles and Abstracts, 127–128.

Grim, R.E. & Bradley, W.F. (1952): The illite clay minerals (abstract). In International Geological Congress, Report on 18th Session, Great Britain, 1948. Part XIII, Section M, 302.

Grim, R.E., Bray, R.H. & Bradley, W.F. (1937): The mica in argillaceous sediments. American Mineralogist, **22**: 813–829.

Gyarmati, P. (1977): Intermediate volcanism in the Tokaj Mts. MÁFI Évkönyve, **58**: 1–196 (in Hungarian with extended English abstract).

Gyarmati, P., Perlaki, E. & Pentelényi, L. (1976): Geological map of the Tokaj Mts., 1: 50,000. Budapest: Geological Institute of Hungary (in Hungarian).

Harman, M. & Chovanec, V. (1980): Microstructures of opal from Dubník locality, Eastern Slovakia and their relation to opalization. Mineralia Slovaca, **13**: 209–220 (in Slovak with English and Russian abstracts).

Hartikainen, A., Horváth, I., Ódor, L., Ó Kovács, L. & Csongrádi, J. (1992): Regional multimedia geochemical exploration for Au in the Tokaj Mountains, Northeast Hungary. Applied Geochemistry, **7**: 533–546.

Hedenquist, J.W. (1987): Mineralization associated with volcanic-related hydrothermal systems in the circum-Pacific basin. Trans. of the 4th Circum-Pacific Energy and Mineral Resources Conf., Singapore, 513–524.

Hedenquist, J.W., Izawa, E., Arribas, A. & White, N.C. (1996): Epithermal gold deposits: Styles, characteristics, and exploration. Resource Geology Special Publication, **1**. Tokyo: Komiyama Printing Co., 165–182.

Hedenquist, J.W. & Arribas, A., Jr. (1999) (eds): Epithermal systems and gold mineralization in volcanic arcs. 3rd Freiberg Short Course in Economic Geology, 13–17 December 1999, Freiberg.

Henley, R.W. & Ellis, A.J. (1983): Geothermal systems ancient and modern: a geochemical review. Earth-Science Reviews, **19**: 1–50.

Henning, K.-H. & Störr, M. (1986): Electron micrographs (TEM, SEM) of clays and clay minerals. Schriftenreihe für geologische Wissenschaften, **25**. Berlin: Akademie-Verlag, 350 p.

Hofmann, U., Jacob, A. & Loofman, H. (1941): Untersuchung der Tonfraktion der Böden mit dem Elektronen-Mikroskop. Bodenkunde und Pflanzenernährung **25**: 257–271.

Hofmann, U., Endell, J. & Maegdefrau, H. (1943): Die Einheitlichkeit des glimmerartigen Tonminerals Sárospatit. Berichte der Deutschen Keramischen Gesellschaft, **24**: 339–344.

Horváth, F. (1993): Towards a mechanical model for the formation of the Pannonian Basin. Tectonophysics, **226**: 333–357.

Kákay-Szabó, O. (1983): Reinvestigation of mauritzite. Földtani Közlöny, **113**: 333–356. (in Hungarian with German absrtact).

Kiss, L. & Takáts, T. (1963): Mineralogical and petrological study of the material of the Füzérradvány illite mines with respect of the fine ceramic industry. Építésanyagipari Központi Kutató Intézet, Tudományos Közlemények, **10**: 1–62. (in Hungarian).

Koděra M. *et al.* (1990): Topographical mineralogy of Slovakia. 1, A-Kl. Bratislava: Veda, 577 p (in Slovak).

Kovalenker, V.A., Jeleň, S., Genkin, A.D., Ďuďa, R., Kotuľák, P., Malov, V.S. & Sandomirskaja, S.M. (1988): Metallic minerals of productive assemblages of the Zlatá Baňa deposits (eastern Slovakia); specialities of chemical composition. Mineralia Slovaca. **20**: 481–498.

Kovalenker, V.A., Jeleň, S., Háber, M., Ďuďa, R., & Prokofiev, V.Ju. (2000): Mineral parageneses, fluid inclusions and stable isotopes studies of Au–Ag base metal mineralization of Banská Štiavnica and Zlatá Baňa stratovolcanos: A comparison, Mineralia Slovaca, **32**: 249–250.

Kozma, P. (2000): Grape and its production I. Budapest: Akadémiai Kiadó, 270 p (in Hungarian).

Kratochvíl, T., Sucha, V., Adamcová, R., Janega, A. & Mátyás, T. (2008): Mineral composition and physical properties of altered rhyolite tuff from selected deposits of the southern part of the Tokaj Mts. (Hungary). Mineralia Slovaca, **40**: 45–52.

Kulcsár, L. & Barta, I. (1971): Petrological studies on the laccolith of the Mulató Hill – Barna Máj, Erdőbénye). Acta Geographica Debrecina, **15–16**: 39–72 (in Hungarian).

Laposa, J. & Dékány, T. (1999): From cellar to cellar. Budapest: Mezőgazda Kiadó, 163 p (in Hungarian with English abstract).

Lexa, J. (1999): Outline of the Alpine geology and metallogeny of the Carpatho-Pannonian region. In Molnár, F., Lexa, J. & Hedenquist, J.W. (eds): Epithermal mineralization of the Western Carpathians. Society of Economic Geologists, Guidebook Series, **31**: 65–108.

Lexa, J. & Kaličiak, J. (2000): Geotectonic aspects of the Neogene volcanism in Eastern Slovakia, Mineralia Slovaca, **32**: 205–210.

Maegdefrau, E. (1941): Die Gruppe der glimmerartigen Tonmineralien. Sprechsaal für Keramik-Glas, **74** (39): 369–372, 381–383, 393–396, 399–401.

Maegdefrau, E. & Hofmann, U. (1937): Glimmerartige Mineralien als Tonsubstanzen. Zeitschrift für Kristallographie, **98**: 31–59.

Mátyás, E. (1966): Geologic and mining conditions of the Upper Sarmatian freshwater basin at Rátka. Földtani Közlöny, **96**: 27–41 (in Hungarian with German abstract).

Mátyás, E. (1972): Geology and economic geology of the ceramic raw materials in the Tokaj Mts. Manuscript in Hungarian, available at the Department of Mineralogy, Eötvös L. universit, Budapest, Hungary. 127 p.

Mátyás, E. (1973): Geologic and mining conditions around Mád. Bányászati és Kohászati Lapok, Bányászat, **106**: 55–66 (in Hungarian).

Mátyás, E. (1974a): Volcanic and postvolcanic processes in the Tokaj Mts. on the basis of geological data of raw material prospecting. Acta Geologica Hungarica, **18**: 421–455.

Mátyás, E. (1974b): A recently explored illite-rich high-quality clay deposit at Füzérradvány. Bányászati és Kohászati Lapok, Bányászat, **107**: 187–196 (in Hungarian).

Mátyás, E. (1979a): Mining geology of the non-metallic mining industry in the Tokaj Mountains. Földtani Közlöny, **109**: 488–506. (in Hungarian with English abstract).

Mátyás, E. (1979b): Guide to the excursion in the Tokaj Mountains. 10th Kaolin Symposium, IGCP Project No. 23, "Genesis of Kaolin", Budapest, 1979. 63 p.

Molnár, F. (1993): Genesis of epithermal mineralization of the Tokaj Mts. on the basis of fluid inclusion studies. Unpublished PhD Thesis, Eötvös Loránd University, Budapest, Hungary (in Hungarian).

MOLNÁR, F. & TAKÁCS, J. (1993): Silica minerals of Mulató Hill, Erdőbénye (NE Hungary). Topographia Mineralogica Hungariae, **1**: 19–40 (in Hungarian with English abstract).

MOLNÁR, F. & ZELENKA, T. (1995): Fluid inclusion characteristics and paleothermal structure of the adularia-sericite type epithermal deposit at Telkibánya, Tokaj Mts., northeast Hungary. Geologica Carpathica, **46**: 205–215.

MOLNÁR, F., ZELENKA, T., MÁTYÁS, E., PÉCSKAY, Z., BAJNÓCZI, B., KISS, J. & HORVÁTH, I. (1999): Epithermal mineralization of the Tokaj Mountains, Northeast Hungary: Shallow levels of low-sulfidation type systems. In Molnár, F., Lexa, J. & Hedenquist, J.W. (eds): Epithermal mineralization of the Western Carpathians. Society of Economic Geologists, Guidebook Series, **31**: 109–153.

NADEAU, P.H., WILSON, M.J., MCHARDY, W.J. & TAIT, J.M. (1984): Interstratified clays as fundamental particles. Science, **225**: 923–925.

NAGYMAROSY, A., BAKACSI, ZS. & ZELENKA, T. (2004): Geology and pedology of vineyards of the Tokaj Oremus Ltd. Manuscript. Budapest: Geo-Logic Bt, 203 p (in Hungarian).

NEMECZ, E. (1973): Clay minerals. Budapest, Akadémiai Kiadó. 507 p. (in Hungarian).

NEMECZ, E. (1981): Clay minerals. Budapest, Akadémiai Kiadó. 547 p.

NEMECZ, E. & VARJÚ, GY. (1963): Formation of Na-bentonite, clinoptilolite and potassium feldspar from the rhyolite tuff of the Szerencs Bay. Földtani Közlöny, 93: 77–91 (in Hungarian with German abstract).

NEMECZ, E. & VARJÚ, GY. (1970): Chemical and structural properties of Sárospatakites (illite/montmorillonite). Földtani Közlöny, **100**: 11–22. (in Hungarian with English absrtact).

NÉMETH, K., PÉCSKAY, Z., MARTIN, U., GMÉLING, K., MOLNÁR, F. & CRONIN, S.E. (2008): Hyaloclastites, peperites and soft-sediment deformation textures of a shallow subaqueous Miocene rhyolitic dome-cryptodome complex, Pálháza, Hungary. Geological Society, London, Special Publications, **302**: 63–86.

PANTÓ, G. (1968): Structural-volcanological relationship between the Tokaj Mts. and its foreland. MÁFI Évi Jelentése 1966-ról: 215–225 (in Hungarian with Russian abstract).

PAPP, G. (2004): History of minerals, rocks and fossil resins discovered in the Carpathian region. *Studia Naturalia*, **15**. Budapest: Magyar Természettudományi Múzeum, 215 p.

PATZKÓ, Á. & SZÁNTÓ, F. (1983): Peptisability and organophilisability of Füzérradvány illite. MFT Illit ankét (Symposium on Illite of the Hungarian Geological Society), Zamárdi, 1983, Programme, 23 (in Hungarian).

PÉCSKAY, Z. & MOLNÁR, F. (2002): Relationships between volcanism and hydrothermal activity in the Tokaj Mountains, northeast Hungary, based on K-Ar ages. Geologica Carpathica, **53**: 303–314.

PÉCSKAY, Z., BALOGH, K., SZÉKY-FUX, V. & GYARMATI, P. (1986): Geochronological investigations on the Neogene volcanism of the Tokaj Mountains. Geologicky Zborník – Geologica Carpathica, **37**: 635–655.

PÉCSKAY, Z., LEXA, J., SZAKÁCS, A., BALOGH, K., SEGHEDI, I., KONEČNÝ, V., KOVACS, M., MÁRTON, E., KALIČIAK, M., SZÉKY-FUX, V., PÓKA, T., GYARMATI, P., EDELSTEIN, O., ROŞU, E. & ŽEC, B. (1995): Space and time distribution of Neogene-Quaternary volcanism in the Carpatho-Pannonian Region. Acta Vulcanologica, **7**: 15–28.

PÉCSKAY, Z., LEXA, J., SZAKÁCS, A., SEGHEDI, I., BALOGH, K., KONEČNÝ, V., ZELENKA, T., KOVACS, M., PÓKA, T., FÜLÖP, A., MÁRTON, E., PANAIOTU, C. & CVETKOVIĆ, V. (2006a): Geochronology of Neogene-Quaternary magmatism in the Carpathian arc and Intracarpathian area: a review. Geologica Carpathica, **57**: 511–530.

PÉCSKAY, Z., MOLNÁR, F., ITAYA, T. & ZELENKA, T. (2006b): Geology and K-Ar geochronology of illite from the clay deposit at Füzérradvány, Tokaj Mts., Hungary. Acta Mineralogica-Petrographica (Szeged), **46**: 1–7.

PÓKA, T. (1988): Neogene and Quaternary volcanism of the Carpathian-Pannonian region: changes in chemical composition and its relationship to basin formation. In Royden, L.H. & Horváth, F. (eds): The Pannonian Basin – a study in basin evolution. American Association of Petroleum Geologists Memoir, **45**: 257–277.

RADULESCU, D.P. & SĂNDULESCU, M. (1973): The plate tectonics concept and the geological structure of the Carpathians. Tectonophysics, **16**: 155–161.

REPČIAK, M. (2005): Deposit of the precious opal Dubník–Libanka. In Žec, B. et al. (eds): Excursion guide to SGS congress, Zemplínska Šírava–Medvedia hora, 98–101 (in Slovak).

REYNOLDS, R.C., JR. (1992): X-ray diffraction studies of illite/smectite from rocks, <1 μm randomly oriented powders, and <1 μm oriented powder aggregates: the absence of laboratory-induced artifacts. Clays and Clay Minerals, **40**: 387–396.

ROHÁLY, G. & MÉSZÁROS, G. (eds) (2001): Rohály's Wine Guide Hungary, Budapest: Akó Kiadó, 296 p.

ROHÁLY, G., MÉSZÁROS, G. & NAGYMAROSY, A. (2003): Terra benedicta – The land of Hungarian wine. Tokaj and beyond, Budapest: Akó Kiadó, 247 p.

ROHÁLY, G., MÉSZÁROS, G. & NAGYMAROSY, A. (2004): Terra benedicta – Blesses Land. Budapest: Akó Kiadó, 272 p (in Hungarian).

ROYDEN, L.H. (1988): Cenozoic tectonics of the Pannonian basin system, In Royden, L.H. & Horváth, F. (eds): The Pannonian Basin – a study in basin evolution. American Association of Petroleum Geologists Memoir, **45**: 27–48.

RÓZSA, P. (1993): Petrography of the laccolith of Mulató Hill, Erdőbénye (NE Hungary). Topographia Mineralogica Hungariae, **1**, 13–17 (in Hungarian with English abstract).

ŠALÁT, J. & ONČÁKOVÁ, P. (1964): Perlite, their occurrences, petrochemistry and use. Bratislava: Vydavateľstvo Slovenskej akadémie vied, 147 p (in Slovak).

SALTERS, J.M., HART, S.R. & PANTÓ, GY. (1988): Origin of Late Cenozoic volcanic rocks of the Carpathian Arc, Hungary, In Royden, L.H. & Horváth, F. (eds): The Pannonian Basin – a study in basin evolution. American Association of Petroleum Geologists Memoir, **45**: 279–292.

SCHOEN, R., WHITE, D.E. & HEMLEY, J.J. (1974): Argillization by descending acid at Steamboat Springs, Nevada: Clays and Clay Minerals, **22**: 1–22.

SEDLETZKY, I.D. (1940): On the principles of classification of argillaceous minerals. Comptes Rendus (Doklady) de l'Académie des Sciences de l'URSS **26** (3): 240–243.

SEGHEDI, I., DOWNES, H., SZAKÁCS, A., MASON, P.R.D., THIRLWALL, M.F., ROŞU, E., PECSKAY, Z., MÁRTON, E. & PANAIOTU, C. (2004a): Neogene-Quaternary magmatism and geodynamics in the Carpathian-Pannonian region: a synthesis. Lithos, **72**: 117–146.

SEGHEDI, I., DOWNES, H., VASELLI, O., SZAKÁCS, A., BALOGH, K. & PÉCSKAY, Z. (2004b): Post-collisional Tertiary–Quaternary mafic alkalic magmatism in the Carpathian–Pannonian region: a review. Tectonophysics, **393**: 43–62.

SEGHEDI, I., DOWNES, H., HARANGI, S., MASON, P.R.D. & PÉCSKAY, Z. (2005): Geochemical response of magmas to Neogene-Quaternary continental collision in the Carpathian-Pannonian region: A review. Tectonophysics, **410**: 485–499.

SILLITOE, R.H. (1993): Epithermal models: Genetic types, geometrical controls and shallow features, In Kirkham, R.V., Sinclair, W.D., Thorpe, R.I. & Duke, J.M. (eds): Mineral deposit modeling. Geological Association of Canada Special Paper, **40**: 403–417.

ŚRODOŃ, J. (1980): Precise identification of illite/smectite interstratifications by X-ray powder diffraction. Clays and Clay Minerals, **28**: 401–411.

ŚRODOŃ, J. (1984): X-ray powder diffraction identification of illitic materials. Clays and Clay Minerals, **32**: 337–349.

ŚRODOŃ, J., ELSASS, F. MCHARDY, W.J. & MORGAN, D.J. (1992): Chemistry of illite-smectite inferred from TEM measurements of fundamental particles. Clay Minerals, **27**: 137–158.

ŠTOHL, J., LEXA, J., KALIČIAK, M. & BACSÓ, Z. (1994): Genesis of stockwork base metal mineralizations in the Neogene volcanics of West Carpathians. Mineralia Slovaca, **26**: 75–117 (in Slovak).

ŠUCHA, V., KRAUS, I., MOSSER, C., HRONCOVÁ, Z., SOBOLEVA, K.A. & ŠIRÁŇOVÁ, V. (1992): Mixed-layer illite/smectite from the Dolná Ves hydrothermal deposit, the Western Carpathians Kremnica Mts. Geologica Carpathica – Clays, **1**: 13–19.

SZABÓ, J. (1867): Tokaj-hegyaljai album / Tokaj-hegyaljaer Album / Album de la Tokay-hegyalja / Album of the Tokay-hegyalja. Budapest: Tokaj-Hegyaljai Bormívelő Egyesület, 185 p (in Hungarian, German, French and English).

SZABÓ, CS., HARANGI, SZ. & CSONTOS, L. (1992): Review of Neogene and Quaternary volcanism of the Carpathian-Pannonian region. Tectonophysics, **208**: 243–256.

SZAKÁLL, S. & KOVÁCS, Á. (1993): Accessory minerals of the Mulató Hill, Erdőbénye. Topographia Mineralogica Hungariae, **1**: 69–85 (in Hungarian with English abstract).

SZEGEDI, Á. (1988): Mixed layer character of "illites" from Füzérradvány, Hungary. In Konta, J. (ed.): Proceedings of Tenth Conference on Clay Mineralogy and Petrology, Ostrava 1986, 249–254. Praha: Univerzita Karlova.

SZÉKY-FUX, V. (1970): The Telkibánya mineralization and its Intra-Carpathian connections . Budapest: Akadémiai Kiadó, 266 p (in Hungarian with English abstract).

TOKODY, L. (1962): Mauritzit ein selbständiges Mineral. Annales Historico-Naturales Musei Nationalis Hungarici, **54**: 27–30.

TOKODY, L., MÁNDY, T. & NEMESNÉ VARGA, S. (1957a): Mauritzit, a new mineral from Erődénye. Annales Historico-Naturales Musei Nationalis Hungarici, Series Nova, **8**: 17–21 (in Hungarian)

TOKODY, L., MÁNDY, T. & NEMES-VARGA, S. (1957b): Mauritzit, ein neues Mineral von Erdőbénye (Ungarn). Neues Jahrbuch für Mineralogie, Monatshefte, 33–39.

UHLÍK, P., KRAUS, I., BAČO, P., HONTY, M. & MADEJOVÁ, J. (2002): Marekanite – Streda nad Bodrogom. Slovensko-česko-polské mineralogicko-petrograficko-ložiskové dni, Košice: F-BERG TU, 36.

VEBLEN, D.R., GUTHRIE, G.D., JR., LIVI, K.J.T. & REYNOLDS, R.C., JR. (1990): High-resolution transmission electron microscopy and electron diffraction of mixed-layer illite/smectite: experimental results. Clays and Clay Minerals, **38**: 1–13.

VICZIÁN, I. (1985): Diagenetic transformation of mixed-layer illite/smectites in deep zones of the Pannonian Basin (Hungary). In 5th Meeting of the European Clay Groups, Prague, Czechoslovakia, 1983. Praha: Univerzita Karlova, 135–140.

VICZIÁN, I. (1996): New results in the study of the Füzérradvány illite. Földtani Közlöny, **126**: 263–266 (in Hungarian).

VICZIÁN, I. (1997): Hungarian investigations on the "Zempleni" illite. Clays and Clay Minerals, **45**: 114–115.

VICZIÁN, I. (2002): Sarospatite: two years earlier. ECGA Newsletter, **5**: 56.

WEISZBURG, T., BADA, G., DÓDONY, I., JÁNOSI, M., LOVAS, GY., NAGY-BALOGH, J., NAGY-CZAKÓ, I., NAGY, S. & PAPP, G. (1993a): "Mauritzite", a special saponite variety from Erdőbénye, NE Hungary. Topographia Mineralogica Hungariae, **1**: 57–68 (in Hungarian with English abstract).

WEISZBURG, T., KOVÁCS, Á., BADA, G., JÁNOSI, M., LOVAS, GY., OLASZI, V., PAPP, G. & SZAKÁLL, S. (1993b): Cavity-filling carbonates of Mulató Hill, Erdőbénye, NE Hungary. Topographia Mineralogica Hungariae, **1**: 41–56 (in Hungarian with English abstract).

WILSON, J.E. (1998): Terroir. Mitchel Beazley publ., 336 p.

ŽEC, B. KALIČIAK, M., KONEČNÝ, V., LEXA, J., JACKO, S., JR, BAŇACKÝ, V., KAROLI, S., POTFAJ, M., RAKÚS, M., PETRO, Ľ., SPIŠÁK, Z., BODNÁR, J., JETEL, J., BOOROVÁ, D. & ZLINSKÁ, A. (1997): Explanations to the geological map of the Vihorlatské vrchy and Humenské vrchy Mts., 1:50,000. Bratislava: Geologická služba Slovenskej republiky, 254 p (in Slovak).

ZELENKA, T. (1964): Sarmatian tuff horizons and facies of Szerencs Bay. Földtani Közlöny, **94**: 33–52 (in Hungarian).

ZENTAI, P. (1991): Programme of the regional geophysical survey in the Zemplén Mts. Unpublished Research Report No. 1187. Eötvös Loránd Geophysical Institute, Budapest, Hungary (in Hungarian).

Appendix – Itinerary for IMA2010 HUSK1 Field trip

Thursday, August 19, 2010 (Day 1)

08.00	Departure from Budapest
11.00–13.30	Arrival to Sátoraljaújhely, accommodation in Hotel Kőnig, lunch, introduction to the geology and mineral deposits of the Tokaj Mts.
13.30–14.00	Travel to Pálháza
14.00–15.30	Field stop 1. Perlite quarry at Pálháza, Tokaj Mts., Hungary
15.30–16.00	Travel to Füzérradvány
16.00–17.30	Field stop 2. Illite mine at Füzérradvány, Tokaj Mts., Hungary
17.30–18.00	Travel to Sátoraljaújhely
18.00–19.00	Free time
19.00–19.30	Travel to Sárospatak
19.30–22.00	Rákóczi castle at Sárospatak, Renessaince-style dinner with wine tasting
22.00–22.30	Travel to Sátoraljaújhely, accommodation

Friday, August 20, 2010 (Day 2, programme in Slovakia)

08:00–10:15	Travel to Červenica-Dubník, Slanské vrchy Mts., Slovakia
10:15–13:00	Field stop 3. The Dubník–Libanka precious opal deposit at Červenica, Slanské vrchy Mts., Slovakia
13:00–13:30	Travel to Herľany
13:30–13:45	Field stop 4. The geyser at Herľany, Slanské vrchy Mts., Slovakia
13:45–15:00	Field stop 5. Occurrence of opal near Herľany, Slanské vrchy Mts., Slovakia
15:00–16:00	Travel to Streda nad Bodrogom
16:00–16:45	Field stop 6. Volcanic tuffs with obsidian – marekanite at Streda nad Bodrogom, Slanské vrchy Mts., Slovakia
16:45–17:00	Travel to Viničky
17:00–20:00	Viničky: cellar visit, underground parts of an extrusive rhyolite dome – introduction to wines of the Slovak part of the Tokaj Mts. wine region, with dinner
20:00–20.30	Travel to Sátoraljaújhely, accommodation (Hotel Kőnig)

Saturday, August 21, 2010 (Day 3)

09.00	Departure from Sátoraljaújhely
09.00–09.30	Travel to Mád, Király Hill, Tokaj Mts., Hungary
09.30–11.00	Field stop 7. Kaolinite and alunite mineralization of the Király Hill at Mád, Tokaj Mts., Hungary
11.00–11.30	Field stop 8. Zeolitic tuff of the Suba quarry at Mád, Tokaj Mts., Hungary
11.30–12.00	Travel to Mád, Kerektölgyes
12.00–13.30	Field stop 9. Silica and clay deposits in a hot-spring fed lacustrine basin west of Mád, Tokaj Mts., Hungary
13.30–14.00	Travel to Erdőbénye
14.00–15.00	Field stop 10. The pyroxene dacite laccolith at Erdőbénye, Tokaj Mts., Hungary
15.00–15.15	Travel to Béres Winery, Erdőbénye
15.15–17.15	Field stop 11. Example of a Tokaj terroir and its wine: the Lőcse terroir at Erdőbénye, Tokaj Mts., Hungary
17.15–20.15	Travel to Budapest

INSTRUCTIONS FOR AUTHORS

General

Acta Mineralogica-Petrographica (AMP) publishes articles (papers longer than 4 printed pages but shorter than 16 pages, including figures and tables), notes (not longer than 4 pages, including figures and tables), and short communications (book reviews, short scientific notices, current research projects, comments on formerly published papers, and necrologies of 1 printed page) dealing with crystallography, mineralogy, ore deposits, petrology, volcanology, geochemistry and other applied topics related to the environment and archaeometry. Articles longer than the given extent can be published only with the prior agreement of the editorial board.

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All articles and notes submitted to AMP are reviewed by two referees (short communications will be reviewed only by one referee) and are normally published in the order of acceptance, however, higher priority may be given to Hungarian researches and results coming from the Alpine-Carpathian-Dinaric region. Of course, the editorial board does accept papers dealing with other regions as well, let they be compiled either by Hungarian or foreign authors.

The manuscripts (prepared in harmony of the instructions below) must be submitted to the Editorial Office in triplicate. All pages must carry the author's name, and must be numbered. At this stage (revision), original illustrations and photographs are not required, though, quality copies are needed. It is favourable, if printable manuscripts are sent on disk, as well. In these cases the use of Microsoft Word or any other IBM compatible editing programmes is suggested.

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The different parts of the manuscript need to meet the instructions below:

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The title has to be short and informative. No subtitles if possible. If the main title is too long, an additional shortened title is needed for the running head.

Author

The front page has to carry (under the main title) the full name(s) (forename, surname), affiliation(s), current address(es), e-mail address(es) of the author(s).

Abstract and keywords

The abstract is required to be brief (max. 250 words), and has to highlight the aims and the results of the article. The abstracts of notes are alike (but max. 120 words). As far as possible, citations have to be avoided.

The abstract has to be followed by 4 to 10 keywords.

Text and citations

The format of the manuscripts is required to be: double-spacing (same for the abstract), text only on one side of the page, size 12 Times New Roman fonts. Margin width is 2.5 cm, except the left margin, which has to be 3.5 cm wide. Underlines and highlights ought not be used. Please avoid the use of foot and end notes. Accents of Romanian, Slovakian, Czech, Croatian etc. characters must be marked on the manuscript clearly.

When compiling the paper an Introduction – Geological setting – Materials and Methods – Results – Conlclusions structure is suggested.

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References

The reference list can only consist of published papers, M.Sc., Ph.D. and D.Sc. theses, and papers in press.

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Best, M.G., Christiansen, E.H. (eds.) (2001): Igneous petrology. Blackwell, Edinburgh, 458p.

Upton, B.G.J., Emeleus, C.H. (1987): Mid-Proterozoic alkaline magmatism in southern Greenland: the Gardar province. In: Fitton, J.G., Upton, B.G.J. (eds.): Alkaline Igneous Rocks. Blackwell, Edinburgh, 449–472.

Rosso, K.M., Bodnar, R.J. (1995): Microthermometric and Raman spectroscopic detection limits of CO_2 in fluid inclusions and the Raman spectroscopic characterization of CO_2. Geochimica et Cosmochimica Acta, **59**, 3961-3975.

Szederkényi, T. (1996): Metamorphic formations and their correlation in the Hungarian part of Tisia Megaunit (Tisia Megaunit Terrane). Acta Mineralogica-Petrographica, **37**, 143-160.

Bakker, R.J. (2002): http://www.unileoben.ac.at/~buero62/minpet/Ronald/Programs/Computer.html. Accessed: June 15, 2003.

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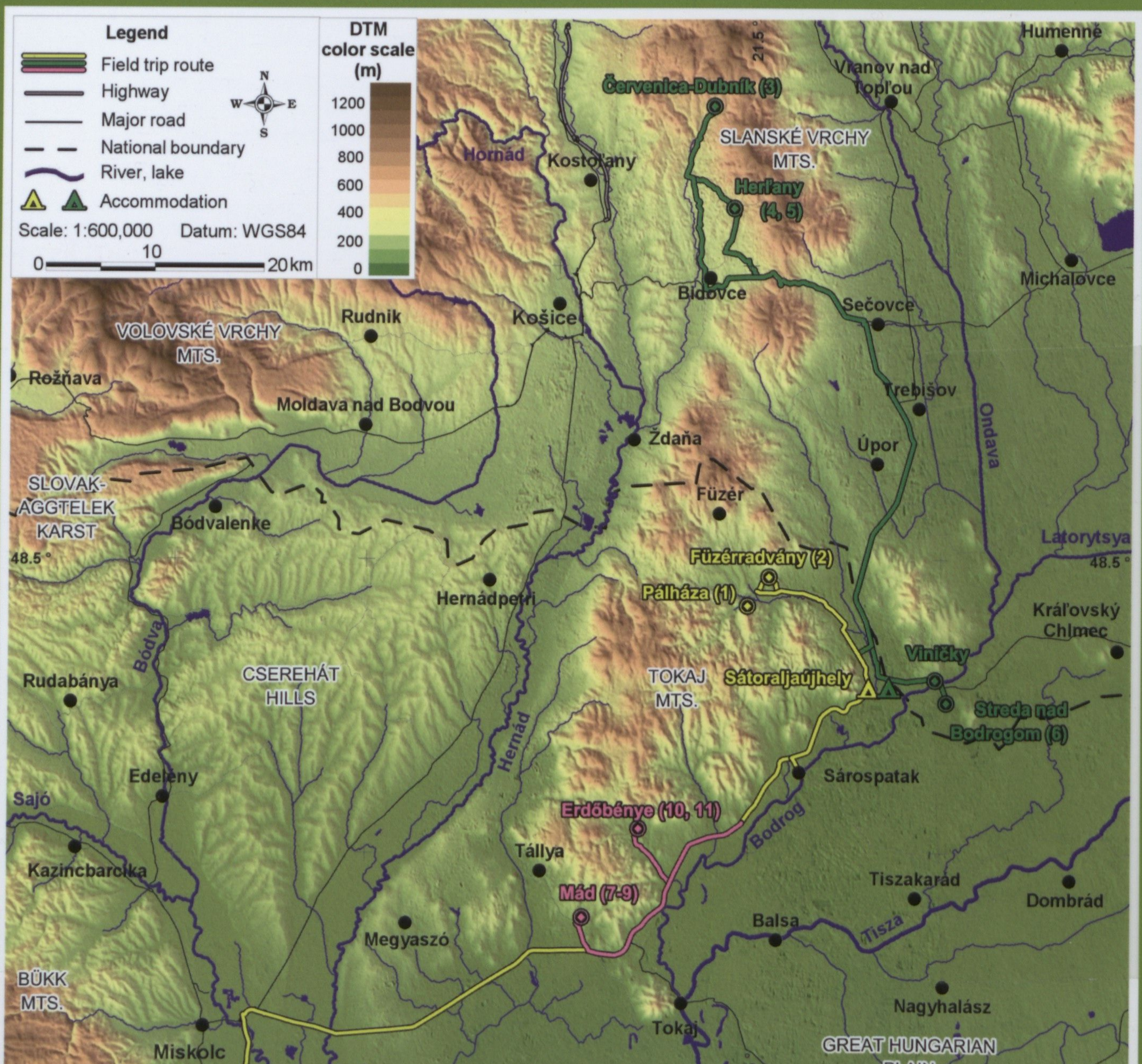

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